CFTRI-MYSORE
4938
Concentrated spr..

8571

Rs 8/=

50363

K. KRISHNAMURTHY
P.O. BOX No 384
MOUNT ROAD.

TI-M3,

Concentrated Spray Equipment, Mixtures and Application Methods

BY

SAMUEL FREDERICK POTTS

DORLAND BOOKS
Caldwell, New Jersey
1958

4938

COPYRIGHT, 1958, BY DORLAND BOOKS

No part of the material covered by this copyright may be reproduced in any form without written permission of the publisher.

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE • MYSORE •
7-5-62
LIBRARY

J;438:K5(D,8)
N58

CFTRI-MYSORE
4938
Concentrated spr..

PREFACE

THIS book covers a relatively new concept of applying agricultural chemicals. In undertaking it, the author has attempted what is unquestionably a severe test of his comprehension of a subject that includes many diverse phases of agricultural chemicals, application equipment, and the agriculture to which they apply.

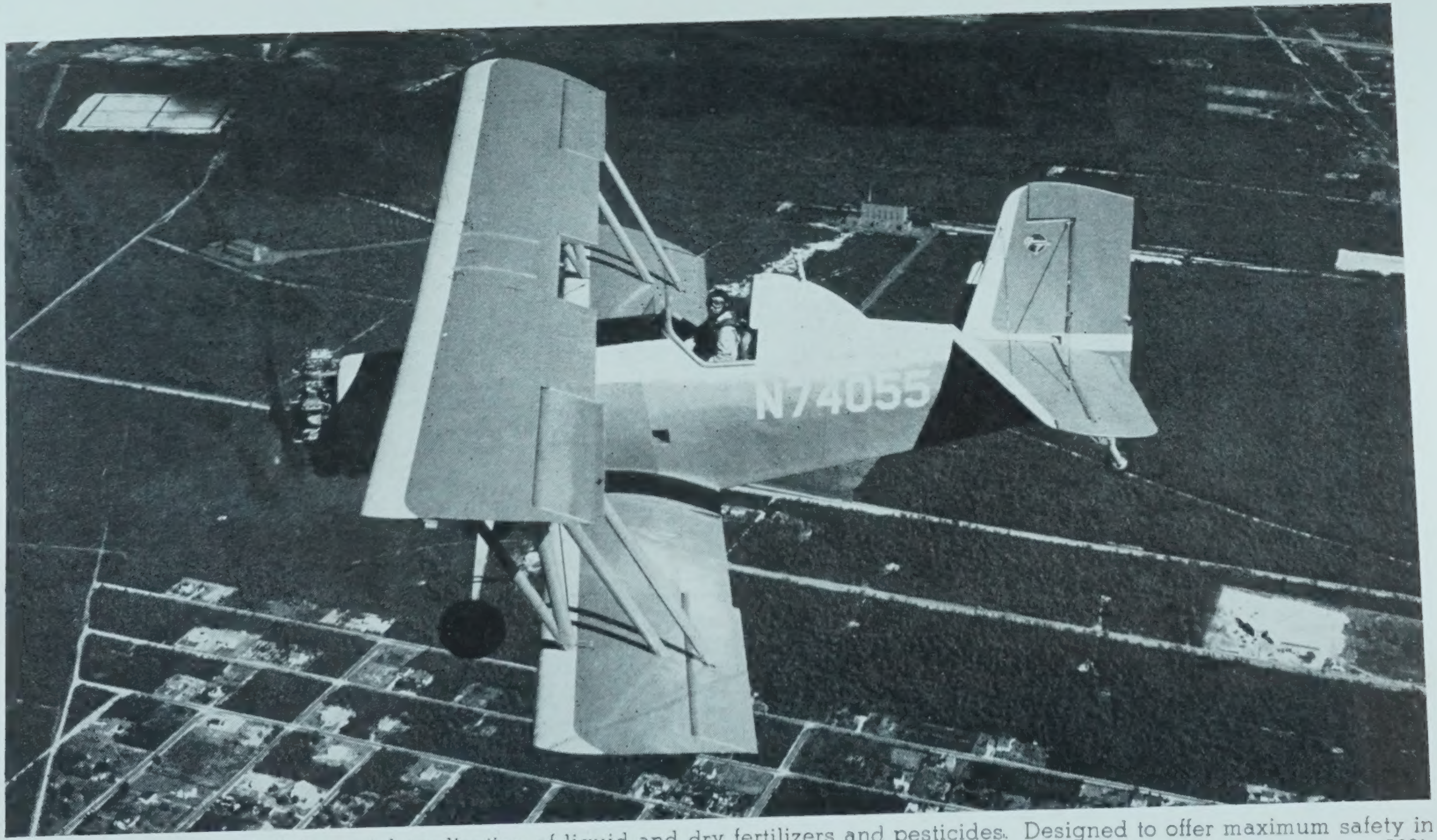
The book is the outcome of a number of years of experience, which have revealed the need of a treatise that would meet the requirements of grower, forester, home owner, municipality, research worker, extension worker, teacher, student, and equipment and chemical manufacturer.

The broad field of concentrated spray application has grown up over night to the extent that several times as many acres are treated with concentrated spray as by conventional spraying and dusting. It includes concentrated spray application of insecticides, fungicides, hormones, herbicides, silvicides, nutrients, fertilizers, and insect disease organisms. This gave rise to the development and use of many types of hand, ground, and aerial application equipment; the development of hundreds of spray formulations and combinations; and the use of new sampling methods and techniques.

The fundamentals and the potentialities of this whole subject, until recently, were very poorly understood even by most research workers in pest control. Moreover, the writer feels that this entire field should be clarified and brought together under one cover. A vast amount of new information is presented, and the text is rich with new ideas and suggestions for further work. Because of its widespread application, the author hopes that millions of Americans will read and benefit from the book. However, it is realized that to accomplish such an ambitious goal, it will be necessary for research workers, extension workers, manufacturers of chemicals and equipment, and others to carry the information and instructions to the potential users. The writer has tried to provide the information for these groups to use in this vast undertaking. For example, every extension worker, county agent, and forester should now be able to write spray schedules, papers, and memoranda and to conduct demonstrations to meet local needs.

Crawford, Miss.
January, 1958

SAMUEL F. POTTS



The Grumman "Ag-Cat" for aerial application of liquid and dry fertilizers and pesticides. Designed to offer maximum safety in operation it was introduced by Grumman Aircraft Engineering Corp., New York, in 1958 (Description on page 593).

TABLE OF CONTENTS

Introduction 1
  Value of the Concentrated Spray Method 1
  Brief History 3
  Acknowledgements 4

CHAPTER I

Terminology 7
  Definitions of particle size and terms relating to concentrated and dilute spray, aerosol, smoke and dust application........ 7
  Concentrate applicators (definition) 11

CHAPTER II

Fundamentals of application 15
  Particle size of insecticides and its relations to application, distribution, and deposit 15
  Dusts 15
  Air-mixed, oil-coated dusts 17
  Concentrated sprays 17
  Application of sprays with ground equipment 21
  Aerial application of sprays 21
  Liquefied gas aerosol sprays 23
  Thermal smoke aerosols 25
  Conclusions prior to 1944 26
Characteristics of spray atomization and deposit 27
Spray-dust application 51
Analysis of mist blower application 57
Special screen deposit tests 65
Effect of evaporation of droplets on deposit 66
Lateral deposit from mist blowers 69
Application to fruit and shade trees 73
Coverage 81
Dual nozzle system for tall trees 87
Swath or strip coverage 88
Rate of coverage and nozzle spray delivery 89

Deposit distribution on low growing vegetation 91
Frequent on-farm calibration of spray machinery needed 94
Aircraft
  Spray pattern, coverage, and deposit, with aircraft 101
  Atomization 101
  Rate of coverage by aircraft 103
  Spray delivery, swath width and coverage rate 104
  Calibration 105
  Corrosion of aircraft structural materials 109
Charts for calculating mixtures 111
Spray formulas 112
Literature cited 114

CHAPTER III

Ground spray equipment 115
  Pumps 116
  Mist blowers 119
  Fans and outlets 119
  Round air outlets and nozzles for tall trees 125
  Nozzles 127
  Tanks and agitators for mist blowers 129
  Other construction details 130
Mechanically produced aerosol from mist blowers 131
Training of operators for tree spraying and general applications 131
Bid specifications for large mist blowers 131
  Mist blower specifications for tall shade trees 135
  Mist blower application for plantation, pecans, mosquitoes, turf 135
Commercial mist blowers for shade trees and general application 137
  Listing for A.B. Farquhar Co. Model Uo. 125 139
  Listing for John Bean Div., FMC, Model No. 100 141
  Listing for Buffalo Turbine Co. Model "F" 141
  Listing for Hardie Mfg. Co. 145
  A lightweight mist blower for row crops, small trees, and general uses 145
  Description of machine 147
  Adaptations 147
  Spray delivery, deposit and drop size tests 153
  Application to row crops with light, 6 hp. mist blower 155
  Cornell row crops mist blower 157
  Large row crop mist blower equipment 159

- Treatment for nursery pests with 6 hp. mist blower 161
  - Red mite tests in nurseries 162
- Mist blower treatment of field crops and pastures 163
  - Corn 163
  - Cotton 163
  - Pastures, clover, and small grain fields 165
- Commercial air blast concentrate machines for vegetables, field crops, pastures 164
  - F. E. Myers row crop concentrate sprayer 164
  - Hardie Jetaire air blast row crop sprayer 165
  - Oliver Iron Age row crop Spray-Blast 167
  - John Bean row crop air sprayer 166

Orchard equipment 169
- Deposit 171
- Hang-on (attachment) blowers 172
- Day versus night spraying 173
- Outlets for fruit tree spraying 173
- Design for special type outlet 183
- Nozzle systems for fruit 185
- Adaptations of existing equipment 187
  - Conversion of orchard duster 187
  - Conversion of old speed sprayer models 187
- Helpful operations information for orchardists 189
- Mist blower status in citrus groves 191
- Use of the lightweight 6 hp. mist blower for fruit 195
  - Application for fruit 195
  - For spraying grape vines 195
  - Blueberries 197
  - Cranberries 199
- Commercial air blast concentrate machines for orchards 199
  - F. E. Myers & Bros. orchard concentrate sprayer 193
  - Oliver Iron Age 193
  - Cardox Aqua-Jet, Model 115 194
  - Hardie Mfg. Co., Model DF-26 194
  - John Bean Division, FMC, Model 40-D 196

Non-Blower, low gallonage equipment 199
- Basic requirements 201
- For cotton and the south 202
  - New nozzle designs 203
  - Other uses 203

Versatility featured 205
Compressed-air hand sprayers for cotton 205

Cultivator spray rig for farm tractor 205
Tanks 207
Tank mountings 208
Pump mountings 211
Line strainer 211
Keep the mixture clean 211
Hose 213
Brooms 213
Commercial low-gallonage machines 217
Boomless nozzle cluster 221
Application to vegetable crops for pest control 221
Equipment used in tests 221
Advantages of low-gallonage sprayers 225
Weed control equipment 229
Equipment for applying insecticides to turf, pastures, clover, and fields of small grain 229
Application of nutrients and fertilizers as sprays with low-gallonage rigs 231

A high clearance self-propelled sprayer for sweet corn 231
Some high-clearance sprayer specifications 232
Boom on high-clearance experimental machine 232
Some factors in operating efficiency 233
Commercial operation costs 234
Other types of machines for corn earworms 235
Formulations for single hand application to individual ears 237
Soils applications for insect pest control 239
Crawfish (crayfish) control 241

Small power and hand equipment

Electric hand blowers 241
Uses for electric hand blowers 242
Knapsack mist blowers 242
Small skid and wheelbarrow models 243
Some pointers on operating the small mist blower 245
Uses for a small skid and wheelbarrow mist blowers 247
Hand equipment for applying concentrates 249
Hand atomizer 249

Compressed air and knapsack sprayers
  Compressed air sprayers 253
  Knapsack sprayers 255
Adaptation for low volume application 257
Hand application to specific crops 259
  Cotton
  Corn
  Vegetables
  For application of herbicides, fertilizers, nutrients
  Mosquitoes and flies
  Flower beds
How to determine amount of spray to use for small equipment 260
Soil pesticide injection equipment 265
  Pressure orifice system 266
  Gravity system with metering element 266
  Gravity head supply vessel with land wheel drive pump ....
  Living plant treatment 269
  Construction materials 269
  Metering element specifications 271
Spray equipment manufacturers 273
Literature cited 274

CHAPTER IV

Aerial equipment 277
Economic and development status 277
History 278
How to spray with aircraft 279
  Spraying personnel 281
  Timing 281
  Safety pointers for the spray-plane pilot 282
  The airborne end 283
If you're an operator 284
  Spray-plane piloting 284
  Spraying and the law 285
  Where to get more information 286
Some equipment facts 286
  Tanks 286
  Pumps 287
  Pipe and fittings 289

  - Main-line valves 289
  - Nozzle shutoff valve 290
  - Other valves 290
- Kinds of airplanes for spraying 291
  - Specifically designed airplanes 293
  - Research and development projects 294
- Installation of spraying equipment 295
  - Spray tank 295
  - Pump 297
  - Propeller, boom stays 299
  - Spray boom, pressure relief valve, pressure gauge 301
  - Shut-off valve 303
- Spray equipment for biplanes 303
  - Tank 303
  - Pump, spray booms 305
  - Spray shut-off valve and pressure gauge, controls 307
- N2S airplane installation 307
- Spinner disk distributor 309
- Other spraying devices 311
- Installation for multi engine planes 313
- Pump and swath requirements for high gallonage 315
- Forest spraying with Stearmans, N3N, and similar planes 316
- Selecting a base of operations 316
- Subdividing and marking of treatment areas 317
- Communications 318
- Pattern and altitude of flight 318
- Observations during spraying 319
- Double swath widths with paired planes 321
- Large scale forest spraying with two- and four-motored bombers 323
- Effect of sizes and shape of area on deposit 326
- Application of low flight levels for crops 327
  - Nozzles used 327
  - Evolution of spray curtain 329
  - Combinations of fine and coarse spray nozzles 331
  - Discussion 332
- Safest known ways to apply herbicides 335
- Pilot training, employment and safety 337
- Summary of accident study 339

Summary of use of protective equipment ... 340
Aerial applicators' responsibilities toward safety and good insect control ... 341
Precautions ... 341
Manufacturers of spraying equipment ... 344
Helicopter application ... 342
Load distribution ... 345
Air blast assembly ... 345
To apply suspensions ... 347
Application of spray-coated dusts ... 349
Limitations in the use of exhaust gases ... 349
Tests with the apparatus ... 350
Applications ... 353
Application with booms and other devices ... 354
Work suggested in agricultural aviation ... 354
Wild life ... 356

CHAPTER V

Mixtures ... 359
Selection of pesticide and mixture ... 360
Cost, labeling ... 360
Requisites of application ... 362
Nozzle tip selection for spraying ... 364
Dilutions in airplane application of concentrate sprays ... 365
Mixing procedure ... 365
Wetting, spreading, and emulsifying agents ... 367
Stickers ... 367
Formulas and description of concentrated mixtures for general use ... 369
Insecticides, inorganic ... 369
Lead arsenate ... 369
Calcium arsenate ... 370
Cryolite ... 370
Organic materials ... 370
Oil concentrates ... 370
Botanical organic poisons ... 371
Nicotine compounds ... 371
Ground derris, cube, and rotenone extracts ... 372

    Pyrethrum and Allethrin powder and extract 372
  Synthetic organic insecticides 373
    Chlorinated hydrocarbons 373
    Foliage burn from use of chlorinated hydrocarbons 374
    Organic phosphates 375
    Dinitro (DN) compounds 375
  Miscellaneous acaricides 376
    Tartar emetic 376
  Inorganic fungicides 376
    Sulfur compounds—Sulfur 376
    Lime-sulfur concentrate 376
    Copper compounds 376
      Basic copper sulfate 376
      Coposil (copper ammonium silicate) 376
      Bordeaux mixture 376
  Organic fungicides 379
    Dichlone 379
    Ferbam 379
    Ziram 380
    Nabam 380
    Agricultural puratized 380
  Tables for calculating dosage, mixture, and gallonage 380
  Household sprays 401
  Compatibility 401
    Compatible spray materials 401

Fertilizer and nutritional sprays 404

Elements to be included in the fertilizer 405
  Fertilizer concentrates for the soil 406
  Foliage application of nutrients 408
  The pro's and con's of foliage feeding 410
  The case against foliage feeding 411
  Foliage feeding tables 412
  Citrus physiological sprays used in Florida 414
    Maturity sprays 415
    Preharvest drop-control sprays 415
  Florida citrus spray schedule 415
  Concentrated spray application of a virus disease to control European pine sawfly 418
Literature cited 419

CHAPTER VI

- Control of weeds and woody plants ... 421
  - Loss in money, resources, and health ... 421
- The organization of weed control ... 424
- Recent advances in chemical weed control research ... 426
- Screening and evaluation studies ... 426
- Chemicals ... 429
  - The phenoxyacetic and phenoxypropionic acids ... 429
  - Leaf penetration of 2,4-D ... 431
  - The benzoic acids ... 433
  - The substituted phenols ... 433
  - The carbamates ... 433
  - The substituted ureas ... 434
  - Other new herbicides ... 434
- Old herbicides and silvicides ... 435
  - Ammate ... 435
  - Sodium arsenite, sodium chlorate ... 436
- Oils ... 436
  - Waste cuts ... 437

Weed control in horticultural crops

  - Asparagus ... 437
  - Beans, beets ... 438
  - Cabbage, cauliflower, collards, kale, rape, broccoli, turnip, mustard, lettuce, and in general, vegetables belonging to the genus *Brassica*. 439
  - Carrots, celery, dill, parsnips, and parsley ... 439
  - Cantaloupes, cucumbers, muskmelons, and watermelons ... 439
  - Onions ... 440
  - Brambles, grapes, strawberries ... 440
  - Nursery stock ... 441
- Weed control in field crops ... 441
  - Corn, pre-emergence treatment ... 441
  - Post-emergence treatment ... 442
  - Rice ... 442
  - Cotton ... 443
  - Cotton, pre-emergence treatment ... 445
  - Post-emergence treatment ... 448
    - Precautions ... 450

- Soybeans (southern area) 451
- Permanent pasture 451
- Turfs and lawns 452
  - Crabgrass 452

Chemical defoliation and desiccation with concentrated sprays 453

Chemical defoliation of cotton 455
- What is defoliation 455
- Defoliation versus desiccation 455
- Why defoliate? 455
- Timing—Key to profitable defoliation 456
- Condition of the plant 457
- Timing for mechanical harvesting 457
- Boll rot 457
- Weather conditions 458
- Types of defoliants 458
- Application 459
- Defoliation in different areas 459

Desiccated seed crops with concentrated sprays 461

Health problems 462
- Ragweed 465
- Poison ivy 465
- Other health offenders 465

Highways and herbicides 466
- New type of highway 466
- Use of herbicides 467
- Operation along roadways 469
- Weed and brush control along utility lines 473
  - Classification of treatment 474
  - Foliage sprays 475
  - Cost 475
  - Equipment and application methods 476
  - Public relations aspects 478
  - Wild life 478

Silvicides as a forest management tool 479

Aerial application for control of brush and trees in the Southwest 481
- Plant factors 482
  - Recommendations 482

Species and types with limited information on control by aerial methods 484
  Pine-Hardwood type 484
  Bottomland hardwoods 484
  Shin oak (Edwards Plateau) 484
Soil factors 484
Climatic factors 485
Application factors 485
Glossary of common herbicide terms 487
Literature cited 492

CHAPTER VII

Aerosols 493
  Liquefied gas aerosols—Scope and limitations 493
  Insecticidal aerosols 495
    Health hazards 496
    Greenhouse aerosols 496
    Field aerosols 498
  Livestock 499
Thermal aerosols 501
Field-model aerosol machines 501
Nozzle-type machines 502
  Gas atomizers 502
  Pressure nozzles 507
  Rotating disks 507
  Shattering machines 508
Aerosol generator for 1½ horsepower motors 508
Windborne aerosols 509
Deposition of fine windborne sprays and aerosols 511
Swath width 511
Particle size 512
Dosage 513
Formulations 514
Method of applying aerosols 514
Literature cited 515

CHAPTER VIII
APPENDIX

Determining particle size of aerosols and fine sprays 517
  Preparation of slides 517

  Deposition of particles on slides 518
  Determination of particle size 519
Procedure for measuring spread factor of oil droplets on oleophobic slides 521
  Spread factor ratios 522
Thin-coated carbon slides 522
A method of determining particle size of liquefied-gas aerosols.... 523
  Deposition of particles on slide 523
  Determination of particle size 525
A photographic method for recording size of spray drops 526
  Photographing the drops 526
  Measuring and counting the drops 526
  Determination of spread factor 529
  Computations 529
  Advantages of the photographic method 529
Determining the depositing efficiency of sprays 531
  Test procedure 531
Other provisions for sampling spray patterns 532
  Samples from conventional nozzles spraying under direct pressure 533
  Measuring drop size indoors by the settling rate 533
Laboratory apparatus for producing drops of uniform size 535
  Vibratory apparatus 535
  Construction 535
  A rotary device to develop uniform drops 537
Determination of spray deposit 538
Dye method for determining spray deposition 539
  Method of analysis 539
Determining distribution of lead arsenate and lead acetate 542
Method of recording copper distribution on sprayed leaves........ 543
Mass and measurements 543
  Unit of mass 544
  Capacity—liquid measure 545
Equivalents for teaspoonful, tablespoonful, and cup 546
  Linear, square, and cubic measure 547
  Units of length 548
  Units of area 548
Diluting insecticidal chemicals 549
  Powdered material 549

Liquid material 549
Dilution of liquids 549
Concentration on the basis of percentage of toxicant 550
Emulsions and solutions, diluting by parts 551
Weight-volume relationships in dosage estimation 553
Temperature conversion 554
Courses of instruction 565
Analysis of the problem 567
Other groups 571
Possible agencies and instruction 571
Material for instruction 573
Mist blower data sheet (form) 572
Airplane and helicopter spray test (form) 574
Pest control applicator examinations 575
Face of applicator examination form (State of Arizona) Questions 576
Respiratory devices for protection against inhalation hazards of dusts, mists, and low vapor concentrations of certain insecticides 580
Respirators not advised for certain uses 582
Formulation specifications 582
Manufacturers of emulsifiers, wetting agents, and spreaders 583
Check list of newer organic pesticides with some commonly known brand names 585
Literature cited 593

LIST OF TABLES

Chapter II

Table No. *Page*

1 Size and number of droplets deposited per unit area by distributing 1 gallon of liquid uniformly over a surface of 1 acre 18

2 Distance to which droplets of given size and velocity can penetrate still air 30

3 Spray deposits on a vertical wall surface when released at different distances from a stationary liquid-pressure atomizing nozzle 33

4 Spray deposits on a vertical surface when released at different distances from a stationary compressed air-atomizing nozzle 33

5 Output of cone and solid stream type nozzles for given orifice diameters and pressures 36

6 Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 25 p.s.i. using 32 seconds viscosity oil 37

7 Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 50 p.s.i. 38

8 Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 100 p.s.i. 39

9 Atomization of flat spray nozzles without an air blast and at right angles to an air blast of 125 m.p.h. in a 12 inch diameter outlet 40

10 Atomization produced by given air velocities at given pressures using a 12-inch diameter air outlet with nozzles pointing at right angles to air blast 41

11 Air velocities for given air pressures in inches of water 43

12 Atomization of spray from whirljet nozzles ejected at 40 p.s.i. from given directions in a 12-inch diameter outlet with the air stream moving at 125 m.p.h. 44

Table No. *Page*

13 Showing atomization of spray ejected at 40 p.s.i. from two whirljet nozzles at right angles to the air blast of air outlets of different diameter 15

14 Showing atomization produced by different air and liquid orifice size combinations 17

15 Relative DDT deposit on 1 x 3 inch glass slides suspended in a 70-foot elm at given heights from the ground with mist blower or duster delivering 8,000 c.f.m. of air at 135 m.p.h. through a 12-inch diameter outlet 54

16 Air velocity required to overcome gravity of drops having a specific gravity of 1.00, applicable to vertical projection 54

17 Minimum air velocity (m.p.h.) for efficient deposition 56

18 Air velocity, air displacement, and diameter of air stream at given distances from a 12 inch diameter outlet delivering air at 125 m.p.h. 56

19 Showing the percentage of spray recovered on glass slides one inch wide when sprays of given degrees of atomization were delivered to the screen at given velocities 64

20 Showing diameter of drops resulting from the evaporation of the volatile portion of solution or emulsions containing 12.5 per cent by volume of non-volatile liquid or powder 64

21 Showing the effect of evaporation on drop diameter 66

22 DDT residue on samples of alfalfa treated with a 25 h.p. mist blower delivering 7500 c.f.m. of air through a 12 inch diameter outlet [illegible]

23 Deposit distribution through canopy of a 30 foot apple tree for two outlets delivering 8000 c.f.m. of air at 126 m.p.h. velocity 74

24 Deposit distribution through canopy of a 30 foot apple tree using a 6 h.p. mist blower with 5 inch diameter outlet at 1 m.p.h. travel rate 74

25 DDT deposit relationship on elm twigs ⅛ to ⅜ inch in diameter from trees 50 to 80 feet tall, top and lower crown, using equivalent dosages 74

26 Drop sizes on slides at different elevations in an elm tree when delivering air at 126 m.p.h. velocity through a 12

Table No. *Page*

inch diameter outlet, and spray delivery at 40 p.s.i. through four No. 1 whirljet nozzles and one, No. 10 whirljet nozzle 78

27 The DDT deposit and drop size of spray solutions at four elevation levels and for four different directions from the mist blower 78

28 Relative DDT deposit on 1 x 3-inch glass slides suspended in a 70-foot elm at given heights from ground with mist blower delivering 8,000 c.f.m. of air at 125 m.p.h. through a 12-inch diameter outlet 83

29 Seconds required for air stream to reach given heights when delivered at 125 m.p.h. through a 12-inch diameter outlet pointed vertically 84

30 DDT deposit from emulsions on 1 x 3 inch slides in a 70 foot elm tree when using 3 nozzle sizes 85

31 Rate of coverage for given rates of travel and for given widths of swath 85

32 Actual spraying time required to apply given quantities of spray concentrate at given rates of delivery 86

33 Gallons of water delivered per nozzle per hour with several whirljet nozzle sizes 89

34 Gallons of water delivered per minute through orifices, tubes, or jets of given diameter at given pressures per square inch 89

35 Deposition of spray on slides in various positions in low growing vegetation, and in the open at 14 inches above ground using a row crop mist blower. Deposit is in micrograms of lead arsenate per 3 x 3 inch slide. 92

36 Deposit in micrograms per square inch by 3 methods of application on slides placed at 4 different levels in a weed stand 94

37 Showing effect on nozzle size, nozzle position, and aircraft speed on atomization of 5 whirljet nozzles at 40 p.s.i. nozzle pressure 99

38 Number of nozzles required for given spray delivery rates 99

39 Spray delivery requirements in gallons per minute for various application rates, speeds, swath widths for small aircraft 105

Table No. *Page*

40 Spray delivery requirements in g.p.m. for various gallonage rates, speeds, and swath widths, particularly applicable to biplanes and various types larger than piper cubs 106

Chapter III

41 Horse power, weight, and air capacity of mist blowers 120

42 Optimum velocity and volume for round outlets of given diameter for tree application 122

43 Air velocities at given horizontal distances from blowers, delivery through round outlets of given diameter 123

44 Dimensions of slot type outlets and round outlets required to drive air same distance at given velocity 125

45 The volume of spray mixture delivered per acre using the triple outlet at a swath of 15 feet and 2.25 mph travel 151

46 Numerical drop diameter obtained at 30 psi with different types of outlets and nozzles with engine going at full speed 151

47 Comparison of swath width and number of droplets per square millimeter for the triple round outlet versus the fish-tail outlet with 20 p.s.i. at 3 m.p.h. travel, when applying a 25% oil emulsion 154

48 Reduction of aphids *(Macrosiphum solanifolii)* on tomatoes by the application of concentrated sprays, using the triple round outlet and a tractor speed of 2.25 m.p.h. 156

49 Mexican Bean Beetle *(Epilachna varivestis)* population before and after treatment in 4 plots treated at the rate of 4 pounds of 50 per cent Marlate wettable powder in 6 gallons of water per acre and a tractor speed of 2.25 m.p.h. 157

50 Number of trees passed at different driving speeds 191

51 Rate of coverage of trees with machine travelling at given speeds treating both sides of each row 198

52 Dimensions of areas of given size for use in calculating the quantity of spray mixture to apply 259

53 Quantity of spray to apply for given volumes per-acre-rate, and for areas of given size 263

Table No. *Page*

54 Length of rows or strips of given width required to equal fractions of an acre, from 1/1000 acre to one acre 262
55 Quantity of mixture to use for each gallon per acre rate 263
56 Quantities of sprays of different concentrations to apply to obtain various dosages of toxicant per 1000 feet, ceiling, floor, or wall surface 264

Chapter IV

57 Useful data on aircraft 314
58 Basic application data for comparative equipment tests 350
59 Drop size and coverage with various types of equipment 351
60 Swath and deposit distribution data 351

Chapter V

61 Quantities of spray to use in mist blowers and hydraulic sprayers for elm bark beetle control 364
62 Quantities of spray to use in hydraulic sprayers on elms for (1) complete coverage and (2) coverage for defoliators 364
63 Dosages of 6 per cent DDT solution for emulsion required for control of various insects in the Northeastern States and timing of application (100X concentration) Nozzle output: 5 gpm 366
64 Dilution table for cotton sprayers 368
65 The amount of commercial insecticide powder or concentrate and the quantity of actual toxicant required per 100 gallons of (1X) full dilution spray 382
66 Quantities of actual insecticide toxicant to use per 100 gallons of mixture for given concentration 386
67 Swell caused by the addition of powdered pesticides, quantity of water required to make a fluid mixture, and the pounds of wettable powder per gallon of mixure 388
68 Quantities of commercial fungicide for 100 gallons of mixture at given (X) concentrations. 390
69 Quantities of powdered and liquid pesticide to use for given dosages and concentration rates for one quart and one gallon lots 392

Table No. *Page*

70 Quantity of insecticide powder by volume for given weights, when measuring with household utensils 394

71 Quantity of fungicide powder by volume for given weights, when measuring with household utensils 395

72 Dilution quantities for 25% concentrate in 100 gallons of final spray mixture 395

73 Quantities of insecticides to use in making given concentrations for one quart and one-gallon lots with household measuring utensils 396

74 For use in measuring fungicides for one quart and one gallon lots with household measuring utensils 399

75 "Ra-Pid-Gro" feeding spray guide for vegetable crops at 5 lb. Ra-Pid-Gro to 10 gal. water per acre 412

76 Ra-Pid-Gro Feeding Spray Guide for corn, beans, small grains, and hay crops amount to feed per acre 413

77 Spray formulas applying to schedules A and B 416

Chapter VI

78 Some of the crops treated and the cost of chemical weed and brush control, 1953 422

79 Reaction of woody plants to herbicides 486

80 This table is presented as a framework for future expansion of the section on chemicals and abbreviations 490

Chapter VII

81 Effect of particle size on the percent of total insecticides depositing on 100-foot strips across a field when released in a 3-mile wind 512

82 Optimum particle size, in microns mass median diameter, of aerosols for application at different swath widths 513

Chapter VIII

83 Representative count of aerosol particles impinged on microscope slides 520

84 A representative count of aerosol particles setted on a microscope slide 521

Table No. *Page*

85 Spread factor ratios 522

86 Relation of droplet size, number of droplets, and areas covered by one gallon of liquid applied per acre in monodisperse sprays on "billiard table." 538

87 Quantities of insecticidal material giving the same concentration in various quantities of finished spray of IX concentration 550

88 Quantities of wettable powders of different strengths to give sprays or dips containing three concentrations of the toxicant 551

89 Factors for use in estimating surface coverage of residual formulations and gallonage per acre 554

90 Contents of horizontal, cylindrical tanks 556

91 Contents of rectangular tanks 558

92 Conversion table for spray nozzle orifices 558

93 Time required to empty spray tanks of various sizes 559

94 Number of trees per acre in square and hexagonal plantings 559

95 Required nozzle capacities to apply desired number of gallons of spray per acre 560

96 Quantities of spray material of 1X concentration required for trees of various ages in full leaf 563

97 Time required for machines to cover one acre of orchard at various tractor speeds for various planting distances 564

98 Volume of air in trees of various sizes 565

99 Tractor speeds to fill a tree with air 565

100 Calibration for broadcast spraying of herbicides in gallons per acre with Spraying Systems Company nozzles spaced 20 inches apart 568

101 Calibration data for pre- and post-emergence herbicidal spraying systems nozzles 569

LIST OF ILLUSTRATIONS

Figure *Page*

Frontispiece Grumman "Ag-Cat" for agricultural aerial application iv

1 Smoke aerosol application against gypsy moth 25

2 Chart showing spray deposit using nozzle D3-25 at 100 psi 32

3 Chart showing spray deposit using "Teejet" nozzle 50015 at 50 psi 32

4 Chart showing spray deposit using "Teejet" 1.5 at 100 psi 35

5 Pulley arrangement to bring slide holders to top of tree 46

6 Spraying a 70-foot elm in the dormant season 48

7 View of slide holders at 5-foot intervals in pulley arrangement 50

8 Loading slide holders from the ground 52

9 Diagramatic analysis of air stream from 12-inch outlet at 125 mph 59

10 Vertical screen for testing deposit on slides, twigs and other objects 62

11 Small frame for suspending objects for catching deposit samples 62

12 DDT and lead arsenate deposit at given distance horizontally 70

13 Method of obtaining deposit samples at given distances laterally from mist blowers 70

14 A 3-hole outlet for use on 12 to 40 hp mist blower 72

15 Treating rows of nursery stock with 6 hp mist blower mounted on tractor 72

16 Difference in amount of DDT deposit on twigs treated in summer and in dormant period 76

17 Chart comparing air velocity at given distances from two blowers 76

18 25 hp blower-atomizer treating 80-foot red oak 80

Figure *Page*
19 25 hp blower-atomizer treating interior of Yale Bowl for control of mosquitoes 82
20 Dual nozzle outlet operated by two separate shut-off valves 84
21 Deposit slides suspended at given elevations and positions 90
22 Deposit in micrograms per 1x3-inch slide 93
23 Chart showing second test on deposit in micrograms 93
24 N3N-3 biplane dispersing DDT over gypsy moth infested forest 100
25 Nozzle manifold and assembly for 12-inch diameter round air outlet 126
26 Twenty-five horsepower blower-atomizer on trailer 132
27 A. B. Farquhar Model 125 Mist Sprayer treating trees 138
28 Model 100 Rotomist 140
29 Buffalo Turbine Shade Tree Blower mounted on a turntable 140
30 Rotomist 75 for truck or trailer mounting 142
31 Hardie L40 mist blower mounted on a trailer 144
32 Hardie L80 mist blower for truck mounting on turntable 144
33 Mist blower and attachments 146
34 View of mist blower showing operating parts 148
35 Trailer mounted mist blower with triple outlet pointed to the rear of trailer 150
36 Machine mounted in a ½-ton truck on a turntable consisting of tire rim and axle 150
37 Showing turntable base with locking pin 150
38 Triple fishtail outlet giving 180 degree angle of spread 152
39 Mist blower mounted on tractor for treating row crops 152
40 Row crop machine with overhead rotating outlet 158
41 Diagram illustrating swath coverage of spraying row crops 158
42 Treating rows of nursery stock with mist blower on small tractor 160
43 Treating nurseries with machine mounted in half-ton truck 160

Figure *Page*
44 F. E. Myers row crop concentrate sprayer 164
45 Hardie Jetaire air-blast row crop sprayer 164
46 Iron Age air blast row crop unit 166
47 Model 15 RC air spraying attachment for mounting on high pressure sprayers 166
48 Model 12RC Speedair attachment 168
49 F. E. Myers' Silver Cloud Concentrate Sprayer 174
50 Spray delivery from blower, showing height reached by spray 174
51 Quadruple spreader outlets 176
52 Quadruple spreader outlet with 50 degrees included angle 176
53 Triple outlet manifold with outlets forming 70 degree included angle 177
54 Rotating triple outlet developed by J. L. Brann 177
55 Fan-shaped outlet with spreader vanes and nozzle assembly 178
56 The Hardie "Orchard Mist" with T-jets and movable vanes for directing spray 180
57 Speed Sprayer with whirljet nozzles 181
58 Iron Age orchard machine for delivering more air and spray to top than to bottom of tree 182
59 Adjustable, dual orchard type outlet 183
60 The Brann nozzle used in one make of mist blowers 184
61 Spiral nozzles producing atomization outside to reduce clogging 184
62 Aqua-jet nozzle giving break-up by collision of two solid stream jets of liquid meeting at high pressure 184
63 Cyclone duster converted to a concentrate sprayer and sprayer-duster. 186
64 Parts for a typical tractor speedometer assembly 188
65 Treating peach trees with spray from a low position 188
66 A double round outlet for treating rows of grapes 190
67 Myers Orchard Concentrate Sprayer 190
68 Myers Orchard Concentrate "Hang On" attachment 193
69 Oliver Iron Age Orchard Spra-blast Adaptor Hang-On Applicator 193

Figure *Page*

70 Cardox Agua-jet Model 115 194

71 Hardie Model DF-26 with centrifugal pump 194

72 Model 40-D Speed Sprayer powered by Chrysler industrial V8 engine 196

73 Model 12 Speedaire orchard attachment designed to convert high pressure units into air blast orchard machines 196

74 Diagram of row-crop sprayer unit 200

75 Diagram of low gallonage boom sprayer and auxiliary hand gun attachment 200

76 Combination cultivator and mist sprayer 204

77 Cultivator-low gallonage sprayer with tank drum mounted in front 204

78 One row straddle tractor with vertical tank mounting 206

79 Sketch showing top view for three-point suspension tank mounting 206

80 Pump mount for John Deere A & B 210

81 Plumbing schematic 210

82 Diagram of a commercial low gallonage assembly for tractor mounting 215

83 Assembly instructions for a commercial manifold pump unit 216

84 Parts for "Yellow Devil" sprayer 218

85 Tractor mounted direct drive rotary pump for low gallonage 219

86 Four types of pumps 219

87 Various accessories 220

88 Boomless sprayer with triple-orifice nozzle cluster ... 222, 223

89 Hahn low gallonage sprayer 224

90 An 8-row low gallonage tractor mounted rig treating potatoes 226

91 Rear view of sprayer for coverage of ear zone of sweet corn 227

92 Assembly drawing of high-clearance self-propelled sprayer for sweet corn 228

93 Specially designed trailer for transporting sprayer 230

Figure *Page*

94 Electric mist blower weighing 12 lbs. for indoor, greenhouse and garden 236
95 Side view of electric mist blower 236
96 Re-designed commercial electric unit modified for spraying concentrates 238
97 Redesigned commercial electric blower 238
98 Side view of wheelbarrow mounted mist blower with electric motor 240
99 A two horsepower, 38-pound knapsack mist blower 240
100 Skid model mist blower for mounting on cart, small tractor, truck or wheelbarrow 244
101 Portable mist blower for small area control 244
102 Wheelbarrow model mist blower operated by one man spraying 30-foot apple trees 246
103 Hollow tube liquid orifice located in center of air orifice 248
104 Six and eight ounce graduated cylinders 248
105 Intermittent hand atomizer showing relationship of air orifice to liquid orifice 250
106 Diagram showing structure of intermittent hand atomizer 250
107 Graduated, one ounce hand atomizer with hand pump detached 252
108 Diagram showing structure of compressed air sprayer 252
109 Diagram showing structure of knapsack sprayer 252
110 Knapsack sprayer with 3-nozzle boom and hand operated hydraulic plunger pump 254
111 Compressed air sprayer using CO_2 for pressure 256
112 Chart showing rate of treatment for desired gallons per acre at given spacings 268
113 Equipment assembly showing metering tube and brush 270
114 Back sweep injection knife construction detail 272
115 Larson Air Tractor 276
116 Silhouettes of agricultural aircraft 292
117 Stearman 2002 equipped with centrifugal pump spray boom 293
118 Drawing of tank 296

Figure *Page*
119 Diagram of spray solution circulation 296
120 Attachment of Oberdorfer centrifugal pump 298
121 Pressure relief valve 300
122 Clamp and spray boom 300
123 Tank for front cockpit installation 302
124 Tank bracket front 304
125 Dump valve assembly 304
126 Bearing housing 306
127 Spray booms 306
128 Stearman 2002 Assembly 308
129 Interior of cockpit of Stearman 2002 310
130 Interior of front cockpit of Stearman 3207 312
131 Light boxes for slides; Grid sampling system to determine swath deposit pattern 320
132 Swath width tests 322
133 Airplane spraying for gypsy moth eradication 324
134 Stearman biplane applying spray at low levels for control of pea aphid 325
135 Coarse and fine droplets of DDT-fuel oil spray 328
136 Variations in spray deposit in typical application from uniformly spaced nozzles 328
137 Spray distribution curves for asymmetrical arrangements of nozzles 330
138 Spray distribution curves for applications from evenly spaced nozzles 334
139 Helicopter landing after spraying elms 343
140 Spray tank and air outlet 346
141 Rear view of air blast apparatus 346
142 Flash tests using mist blower weed blow torch 348
143 Autogiro equipped for spray concentrate application 352
144 Trailer frame for transporting helicopter over roads 354
145 Fruit grower chart 402
146 Organization of the Weed Investigation Section 420
147 Trends in the development of herbicides 428
148 Leaf penetration of 2,4-D 431

Figure *Page*

149 Effect of some soil properties on the activity of herbicides 432

150 Weed control in peanuts 438

151 4-Row pre-emergence planting and spraying in cotton 444

152 Highway weed and brush control sprayer 470

153 Applying liquefied gas aerosols containing DDT to field peas 500

154 Todd fog insecticide applicator in action 504

155 Swing fog jet smoke machine weighing 25 pounds empty 504

156 Cross section through nozzle 510

157 Fogging apparatus attached to lawn mower 510

158 Determining the mass median diameter with the 50% point 516

159 Nomograph for determining the spread factor 528

160 Cumulative per cent volume plotted against diameter of drops 530

161 Vibratory apparatus for producing uniform drops 534

162 Hardness and pH values of water in the U. S. 566

INTRODUCTION

THE application of agricultural chemicals in the form of concentrated spray has become big business affecting every man, woman, and child. In North America alone during the past seven years an aggregate of over 150 million acres have been treated with concentrated sprays, and as much as 30 million acres are now being treated annually. The value of the method is indicated in part by the following quotation from *Trees* magazine*:

Value of the Concentrated Spray Method

"THE treatment with concentrated sprays by airplanes, helicopters, low gallonage sprayers, and mist blowers has included the following:

1. Over 12 million acres of forests in the United States and Canada, since 1944.
2. Millions of valuable shade trees, using mist blowers.
3. Millions of acres in this country and abroad to control flies, mosquitoes and other pests of man and livestock. This has prevented or reduced disease and suffering in tens of millions of people in this country and abroad and has saved the lives of hundreds of thousands of others; has increased food production, and has made numerous areas habitable.
4. The treatment of several million acres of cotton annually during the past few years with low gallonage rigs and airplanes.
5. Several million acres of cereal and forage crops and pastures annually, including grasshopper infested areas.
6. Tens of thousands of acres of fruit orchards, using mist blowers.
7. Made possible a 10 million dollar-per-year concentrated spray equipment industry.

---

*Trees, Vol. 14, No. 3, Page 5, 1954.

8. As much as 20 million acres of small grains, corn, pastures, and brush are treated annually with herbicides, using low gallonage concentrate rigs and aircraft."

Although large acreages have been treated, the fact remains that much of this area could have been treated more efficiently and effectively and at a lower cost if the data and information in this publication had been available earlier. Moreover, its publication should hereafter considerably increase acreage treated, increase the effectiveness and value of future applications, and greatly extend the field of use of the method. In practically no phase of agriculture has the method approached its ultimate potential of use in the control of insects and diseases. Agriculturalists estimate that pests and obnoxious weeds are costing the nation at least nine billion dollars annually. A large part of this loss could be averted by the correct application of concentrated sprays. This book includes recent information on equipment for and methods of applying as concentrates the new herbicides, silvicides, foliage nutrients and fertilizers, as well as insecticides and fungicides.

This text is designed primarily to supply potential users, manufacturers, and distributors with general and concise information on the principles involved in the construction and use of ground and aerial equipment, to discuss various types of equipment for various uses, to discuss the kinds of chemicals and formulations, and to point out the fields of usefulness, hazards, and limitations of each. It should be of particular help to research and extension workers and county agents; for preparation of spray schedules by federal and state agencies; for course preparation and class room exercises. It is at least a tentative set of specifications and guides for manufacturers of spray equipment, spray concentrates and ready-to-use mixtures, and methods of handling various types of spray jobs.

The essential information on mixtures includes the requisites of application; phytotoxicity and compatability, methods of preparation, dosage, concentration, gallonage, combination sprays, formulation for specific pests, wetting, spreading and adhesive compounds, and sources of supply for chemicals and equipment.

The first chapter is devoted to a clarification of terminology and to the presentation of basic information on spray atomization, droplet size, distribution and deposit. It forms a basis for the information and illustrations that follow on equipment, formulations, and methods of operation.

Information on particle, droplet, and deposit sampling techniques and methods is given in the appendix.

Brief History

THIS text does not give an extensive bibliography and discussion of articles* appearing in the many publications on the subject. However, it does give the more important findings of certain workers, and references are made to these investigators and their work throughout the text, where it contributes to the value of the presentation. In other words, the author has used primarily his own findings, together with those of his co-workers and cooperators, plus the known findings of others in places where it is useful, so that the whole field of application is covered.

The idea of applying highly concentrated sprays in finely atomized droplets was tried by Potts in 1928, using an orchard duster to apply concentrated spray, oil-coated dust, and "wet" dust or spray-dust atomized into the air stream of a 4-inch diameter discharge pipe. This work was preliminary in nature. Inadequate air volume and velocity restricted the projection of either spray or dust to a height of 35 to 40 feet. However, in spite of numerous "road blocks" and disappointments, the writer never abandoned the idea of developing the method to the stage where it could be utilized on a large scale. When lack of funds and other factors frequently blocked or impeded research on the project, available information, suggestions, and encouragement was passed on to others who might be interested in going into this field. In the early stages, it was not always easy to convert others to the potentialities of the concentrated spray method.

The idea of applying insecticides in concentrated spray form arose from the need for a cheap, rapid method to replace the slow, difficult, expensive task of applying about 600 gallons of spray mixture per acre to woodlands with high pressure hydraulic sprayers. Here, the cost of labor and equipment amounted to 7 to 10 times the cost of insecticide. Dusts applied by aircraft and ground dusters were not satisfactory because of poor deposit, poor adherence, and other factors.

---

*Practically all of these articles apeared after 1945.

This study was initiated for insecticide application by both ground equipment and by aircraft. Many of the fundamentals had to be worked out with ground applicators, such as hand atomizers, air compressers, fans, and direct pressure atomizing apparatus, since aircraft could not be obtained at all times. From 1929 to 1934 the Massachusetts Institute of Technology through Dr. Karl O. Lange made one of their planes available for frequent tests. It was during these studies that a boom with liquid, hydraulic nozzles was developed. The boom of hydraulic pressure nozzles had to be abandoned until 1943 when solutions came into use, because most of the insecticides were in powdered forms, like lead arsenate, which required some pump pressure and tank agitation to prevent clogging. This resulted in the development and temporary use of centrifugal atomizing devices with gravity liquid flow. The spinner apparatus was used on autogiros, and then on airplanes until about 1948.

Acknowledgement

It is not feasible to mention all of the many individuals and companies who contributed much to this development. Special credit, however, should go to the late Dr. P. N. Annand, chief of what was then the U.S. Bureau of Entomology and Plant Quarantine, who made it possible for the author to conduct experiments in cooperation with the Bureau's Division of Truck Crop Insect Investigations, Cereal and Forage Crop Insects, Fruit Insect Investigations, and Insects Affecting Man and Animals; to the Division of Gypsy and Brown-Tail Moth Control for funds and assistance in conducting a number of large scale projects; to the Division of White-Fringed Beetles Control for mechanical facilities and assistance. With C. N. Husman and E. M. Dieffenbach of that Division it was possible to develop two ground machines, and it was with the help of continuous contacts with Mr. Husman at Orlando, Fla., that the first aircraft spraying apparatus was developed for the Division of Insects Affecting Man and Animals in 1943 and 1944 for applying paris green, oils, and DDT solutions for control of mosquitoes. The spectacular results with the DDT application caused the United States Army to initiate extensive aerial application.

A number of state cooperators have helped in making applications, but the writer should give special credit and recognition to

Dr. R. B. Friend and R. A. Spencer of the Connecticut Experiment Station for supplies, assistance and mechanical help. Dr. Friend was active in guiding and promoting the work and Mr. Spencer assisted greatly in developing a number of mist blowers, low gallonage rigs, and spraying apparatus for helicopters. Also, at the Connecticut Station Dr. Philip Garman's guidance and cooperation helped immensely in the fruit insecticide and disease testing program, and B. W. McFarland made a number of pictures.

A number of equipment companies helped by supplying equipment, particularly, John Bean Manufacturing Co., Niagara Sprayer and Chemical Co., and the Homelite Corp. Various chemical companies furnished chemicals for experiments.

Special mention should be made of the part played by Dr. Harold Waters in helping "sell" the low gallonage method to growers, first to grain growers for weed control in the mid west and North Central States, and then to cotton growers.

The Department of Entomology and Plant Pathology of Cornell University did considerable developmental work on ground equipment, and Drs. Charles Palm and J. L. Brann were very helpful in their reviews of the manuscript. The criticisms and suggestions of Drs. F. W. Poos and R. L. Nelson were also particularly helpful.

CHAPTER I

TERMINOLOGY

Definition of Particle Size and Terms Relating to Concentrated and Dilute Spray, Aerosol, Smoke, and Dust Application

THERE has been considerable confusion in defining particle size and in the use of terms relating to concentrated and dilute spray, aerosol, smoke and dust application. Incorrect interpretation and lack of understanding of the fundamentals involved have resulted in much needless waste of time, money, and lack of maximum effective results. It seems timely to suggest definitions for some of the terminology in this particular field of disperse systems and to indicate their proper use.

Particle Size. Thorough understanding of the meaning of particle or drop size and correct methods of recovering and measuring particle samples would help remove the confusion associated with some of the terms that follow. The term particle size has had several meanings, often misconstrued, depending on whether reference is made to radius, diameter, volume ($4.2R^3$), surface area ($3.14d^2$), or density. In stating actual size of round droplets, one should make clear whether radius or diameter is meant, because a droplet with radius of 50 microns* is eight times larger in terms of volume than one with a diameter of 50 microns and 64 times larger than one of 25 microns diameter. A particle of given diameter or volume with a density of 5 is 2½ times as heavy as one having a density of 2, and particles of the same size or density may expose very different surface areas. The term *average diameter* (or average radius) should be qualified, since average diameter can be considered, as either a *mass average diameter, numerical average diameter,* or *mass median diameter.* If all droplets were of the same size, their average numerical, mass, and median diameters would be identical.

The *mass median diameter* is the drop diameter that satisfies the condition that half the spray volume is of drops larger, and half is of drops smaller.

---

*A *micron* is 1/1000 millimeter.

The *mass average diameter* is the diameter of the drop of average volume. A typical spray pattern having a numerical average drop diameter of 40 microns, also gave a mass average drop diameter of 52 microns, and a mass median drop diameter of 56 microns. Over half of the drops were less than 31 microns in diameter.

Mass average diameter, also correctly called *mass median diameter,* is the diameter of the drop whose volume is obtained by dividing the volume of spray in the sample by the total number of drops. The diameter of a sphere of this volume is then found, by the equation:

$$\text{D (diameter in microns)} = Z\sqrt{\frac{\text{volume in cu. microns}}{4.2}}$$

Numerical Average Diameter is found by adding all the drop diameters and dividing by the number of drops. It is always less than the mass average diameter, and most of the volume of the spray pattern is in drops having diameters larger than the numerical average. The volume of a sphere of this diameter multiplied by the total number of drops does not equal the total volume of spray.

In any discussion of particle size the method of obtaining particle samples of spray or dust should be adequately stated or understood by both writer and reader. The importance of indicating the sampling method is illustrated by the fact that when the mass average diameter is greater than approximately 75 microns, nearly complete droplet patterns can be recovered out-of-doors on foliage and microscope slides; but when the mass aervage drop diameter is 10 microns or less, over 95 percent of the drops are too small to deposit on or impinge upon foliage, insects, and slides out-of-doors, thus making it necessary to trap drop samples in the air.

Size of dust particles. The size of dust particles quoted on a package or container refers to the diameter of individual particles, and is not related to the size of dust particles deposited on plants and other objects. This deposit consists mostly of large particle "groups," or "agglomerates" of many particles, since most extremely fine individual dust particles do not ordinarily deposit satisfactorily on plants or insects out-of-doors.

Deposit as related to *contact effect* and *stomach poison* effect. A great deal of confusion has arisen because of a lack of understanding of the relationship of particle size to contact and stomach poison effect. Many assume that an aerosol or spray that is too fine to leave a deposit can be an effective contact poison. With the exception of fumigants, they could not be effective contact toxicants because no particles can kill insects without being deposited on them or on the plants. Whether a contact or stomach poison *effect* is considered, effectiveness is directly dependent on the quantity and distribution of the deposit. *Oil-coated dust* and *air-mixed-oil-coated dust* are terms that should convey two quite different meanings. An *oil-coated dust* is made before application in a mixing device, such as a ball mill. It may contain from 2 to 12 per cent oil by weight, and is applied in the usual manner by conventional dusters. Most materials containing more than 8 to 12 per cent oil or other liquid cannot be dusted. *Air-mixed oil-coated dust* is a new application method in which special spray-dust equipment simultaneously applies and mixes atomized dust and finely atomized oil. For dust to deposit and adhere more effectively it should be coated with 20 per cent or more of oil by weight. Greatest deposit and adherence seems to occur when all of the dust is coated with about 50 per cent oil by weight. *Spray-dust*, and *"wet-dust"* have the same meaning as the above term, except that they also include similar application of water and sprays other than oils.

The terms *dilute*, *ordinary*, or *conventional spray method* refer to ground applications of 75 to 1000 gallons per acre of mixtures of low insecticidal concentration. In the so-called mist-spraying, most of the spray volume is in drops of 400 to 1,500 microns diameter; in solid stream spraying, the drops are 1,000 to 3,000 microns diameter, and water is the carrier when spraying living plants. The volume of spray is sufficient to wet foliage very noticeably, often to the extent of considerable drippage and run-off. Pressure is applied directly to the liquid, as compressed air in the tank of a knapsack sprayer, or hydraulic pressure on the liquid between pump and nozzle in a high pressure power sprayer.

Concentrate application has these necessary characteristics: (1) a low volume (¼ to 15 gallons) per acre, or per unit area, (2) insecticide concentration many times that of any dilute spray mixture of the same insecticide, and (3) fine atomization compared to that for dilute sprays; with most of the spray volume in drops less than 300 microns diameter. The spray can be a *solution*, *emulsion*, or *suspension*. Concentrated sprays can be applied with several types of equipment. Atomization can be accomplished (1) mechanically, with direct pressure through special conventional nozzles, compressed air, air velocity (as from a blower or the forward speed or propeller blast of aircraft), centrifugal devices; (2) liquefied gas; (3) steam or thermal generated smokes, etc.

Atomized spray, atomized oil, vapor-spray and *vapor-dust* are poorly adapted terms used to denote concentrated spray application. Actually, any spray mixture is atomized upon application whether dilute or concentrated. *Vapor dust* and *vapor spray* are incorrect hybrid expressions.

Semi-concentrated sprays are those having an insecticidal concentration of 2 to 7 times that of regular conventional sprays. This often requires an application of 15 to 35 gallons per acre for crops, and 30 to 70 gallons per acre for fruits.

X — concentration means the number of times the concentration of the mixture is greater than the regular conventional spray. For example the conventional spray concentration is X1. Mixtures that are 5, 10, 20, etc., times its concentrtaion are known as X5, X10, X20, etc., concentration.

Aerosol. The word "aerosol" is one of the most incorrectly used terms. Relatively few people have used it correctly or understood its meaning. Physical chemists prefer to designate aerosols as air suspensions of extremely fine, dry or liquid particles of almost colloidal fineness that are considerably less than four microns in diameter and which may remain suspended in the air for hours or even days. Clouds of extremely fine individual dust or smoke particles are typical aerosols. They are not vapors or gases and ordinarily do not pass through the breathing pores of insects. Aerosols will eventually settle out in calm air of a convection-free room or container, but do not deposit out-of-doors to any appreciable extent on plants, insects, and other objects. Therefore, under ordinary conditions, true aerosols are not effective field insecticides. Highly successful field control with "liquefied gas" aerosols is reported, but these are not true aerosols since most of the insect mortality is due to that portion of the atomized concentrate which is in droplet sizes exceeding 15 microns diameter. Aerosols can be made from liquids by mechanical atomization, condensation of thermally generated vapors into "smokes," and by liquefied gas propulsion. In discussions of dusts and atomized sprays, specifications should be made of the particle size or degree of fineness. Small droplets, originally above aerosol size, sometimes become aerosols when allowed to drift in the air long enough for volatile fractions to evaporate.

Smokes are true aerosols, whether the particles are liquid or dry. The particles or droplets are separated. Most of them are one micron or less in diameter in the case of screening smokes, but may be larger in the case of certain other less dense smoke clouds. Under certain conditions the size of smoke particles can be increased greatly, but as soon as the particles grow beyond aerosol size, they are no longer smokes or aerosols and therefore do not appear or behave like smokes.

Vapor is a gasified liquid or solid mixed with air and may be capable of condensation into drops or larger particles, often producing a smoke-like appearance, depending on fineness.

Diameter of particles in liquid-in-air and solid-in-air disperse systems.

Category	Diameter range (microns)	Numerical average diameter (microns)
Liquid-in-air disperse systems		
Spray	150 to 3000	750
Coarse mist spray	51 to 500	175
Medium fine mist spray	60 to 350	75
Fine mist spray	10 to 50	30
"Wet," misty fog	10 to 50	35
"Dry" fog	1. to 10	5
Aersols (fine)	1. and smaller	0.4
Aerosols (coarse)	2 to 4	3.
Solid-in-air disperse systems		
Dust	Larger than 10	....
Cloud	0.1 to 10	....
Smoke (most of particles in aerosol size)	5. and smaller	....
Aerosol	Less than 4 microns	....

Concentrate Applicators

Ground equipment. Many sizes and types of equipment may be used for applying concentrates when equipped with a suitable atomizing nozzle. These include hand atomizers, knapsack sprayers, liquefied gas spray dispersing apparatus, thermal generators, mist blowers, and power driven non-blower type, low gallonage sprayers.

A *liquefied gas sprayer* is an apparatus which disperses a mixture of liquid gas (such as the fluorinated hydrocarbons, methylene chloride, CO_2, etc.) and a pesticide, or some other chemical to be sprayed as a finely atomized concentrate. At ordinary room or spraying temperatures, the liquid gas in the mixture volatilizes and thus generates its own pressure for atomizing and dispersing the spray. The gas output that carries the mist is more nearly comparable in volume with that from small orifice compressed air nozzles, and therefore it cannot project the mist great distances like the air blast of mist blowers.

Thermal generators (mist, fog or aerosol). Thermal generators are applicators that utilize heat to atomize liquid concentrate sprays. They may disperse a fine mist or an aerosol fog. They may or may not have a blower (fan) to drive the droplets to some distance from it. With a blower, they may operate with a breeze, against a contrary wind, or in the absence of any noticeable air movement. When the unit operates with a fan, it is essentially a mist blower that uses heat to assist in atomizing the liquid. Either steam, hot air, hot volatilized oil, or hot metal rings or hot exhaust pipes are employed to atomize the spray liquid.

Mist blowers. A mist blower is a power driven ground machine that disperses highly concentrated sprays in finely atomized (10 to 150 microns) form at low gallonages per acre (or per unit area) with air as the principal carrier instead of water or other liquid carrier.

Low gallonage power concentrate sprayers may be operated without a blower for applying insecticides and herbicides to low growing crops, weeds, and brush. The spray liquid is pumped through low gallonage conventional type (as oil burner) cone or flat spray nozzles at 20 to 100 pounds pressure. This type apparatus is cheaper, lighter, and simpler than blower type apparatus, but has the disadvantage of producing coarser drops, lack of driving power to carry the mist, and is limited to low growing plants.

Compressed air power atomizers use a compressor to develop air pressure for delivering both air and liquid through atomizing nozzles at 10 to 50 pounds pressure for applying concentrates to low growing plants.

A *helicopter mist sprayer* is an airborne mist blower for applying concentrated sprays in which a large volume of low velocity air from large propellers or rotary wings mounted above the aircraft tends to drive the spray mist downward. The spray may be atomized by oil-burner type nozzles with pressures above 25 pounds per square inch (p.s.i.) developed by a pump driven by the helicopter's motor; or it may be atomized by high air velocity from a fan.

An *airplane mist sprayer* is a fixed winged, airborne concentrate applicator, which utilizes the speed of the aircraft to help atomize the spray, and which may or may not utilize pump pressure or the air blast from the propeller of the aircraft engine to atomize it. Power for driving the pump is usually derived from a small airdriven propeller.

CHAPTER II

FUNDAMENTALS OF APPLICATION

Particle Size of Insecticides and Its Relation to Application, Distribution, and Deposit.

RECENT developments in the application of insecticides in the form of smokes, liquefied-gas aerosols, and finely atomized sprays, with equipment operated from the ground and from aircraft, have attracted attention to the significance of particle or droplet size as a factor in determining deposit, distribution, and effectiveness of dusts and concentrated sprays (Potts, 1946). Under field conditions, extremely minute individual particles of finely ground dusts, insecticidal smokes, finely atomized aerosols, and concentrated sprays are not deposited on the surface of plants, insects, and other objects. Such objects are surrounded by a film, or field of resistance, through which minute particles cannot penetrate. An electric field and air cushion around such objects may cause a repulsion of minute particles. Micro-climatic conditions caused by difference in temperature, humidity, and weight of air near such objects produce air currents which carry away minute particles. Deposit is particularly light on warm, sunny days, and often there is a difference in temperature of as much as 10°F. between the sunny and shady sides of a leaf. Less deposit has been noted on the underside of cupshaped or crimped leaves than on the upper surface.

Larger individual particles, whether dry or liquid, as well as groups or agglomerates of small dust particles, are heavy enough to penetrate the film of resistance and make contact with the surface of leaves, insects, and other objects.

Dusts

A series of studies conducted from 1926 to 1935 brought out the following conclusions concerning dusts:

Small individual dust particles do not give a good deposit. Dust clouds consist of mixtures of individual particles and groups, which may be composed of 25 to 300 individual particles (Potts, 1940). Such groups of dust particles may settle on a surface, but do not adhere well. After dust is expelled for a considerable distance from a blower, these groups of particles do not tend to break up, nor do the individual particles in the cloud tend to coalesce.

Dust particles of heavy substances, such as barite, deposit somewhat better than do particles of light materials, such as derris, although from the standpoint of deposit the weight of the individual particles of a material is not as important as the presence of agglomerates in the dust cloud.

Proportionately, more dust is deposited from a cloud of heavy dust expelled from a blower at low velocity than from a cloud of light dust expelled at a high velocity and with a large volume of air.

Dust applied at a high velocity penetrates the resistant film around objects near the blower and deposits on them; however, at several feet from the blower the effect of high initial velocity is lost. This explains, in part, why ground equipment may never be very effective in dusting large trees.

The fineness of a dust, as indicated on the package or container, is not a criterion of its depositing qualities. The following insecticides are listed in descending order of the proportion of dust deposited on the foliage: sulfur, lead arsenate, derris and cube, pyrethrum, and cryolite. Sulfur particles are fairly large, as compared with those of the other materials. Lead arsenate particles are heavy and very fine (mostly less than two microns in diameter), but when applied, this material forms groups of particles. Derris, cube, and pyrethrum dust particles are light and coarse. Cryolite dust has a greater tendency than most materials have to break up into individual particles upon application. It gives a lighter deposit than lead arsenate, but the deposit can be considerably increased by adding 10 or more parts of pyrophyllite to each part of cryolite.

Dust swaths applied by aircraft are often several hundred feet wide, but their effective width is seldom more than 30 to 50 feet, the effectiveness being confined mostly to that part of the swath where a deposit of agglomerates, or particle groups, exists.

The failure to control insects with dusts is due to light deposit and poor adherence, rather than to small quantity of material or small number of particles applied. Even when a dust having a particle diameter of 0.5 to 2 microns is applied at the rate of one pound per acre, although thousands of particles per square millimeter of surface might be available, insect control might not be obtained.

Air-Mixed, Oil-Coated Dusts

When a cloud of finely atomized dust is mixed with a cloud of finely atomized oil, in the absence of pressure or vacuum, there is little tendency for the oil particles to coalesce with the dust particles and only a small percentage of the dust particles are coated with oil. It seems possible that at least the smaller particles may actually repel each other. On the other hand, when an oil or other liquid is atomized by the force of a stream of compressed air (15 pounds pressure or more) which contains the dust, a fairly good coating is obtained. A considerable amount of dust can be coated if the liquid is finely atomized with high-velocity (150 to 300 m.p.h) air from a blower. The coated particles coalesce into groups and adhere to foliage better than do ordinary uncoated dust particles.

Concentrated Sprays

The failure of dusts to deposit and adhere satisfactorily on foliage has led to the development of highly concentrated insecticidal sprays and the application of these concentrates as finely atomized mists. This method permits coverage with a lower volume per acre. Although fine atomization is necessary to obtain adequate distribution with low rates of application, the droplets must be large enough to give a satisfactory deposit on foliage and insects. There is little deposit of droplets less than 20 microns in diameter; in fact, very few are deposited unless their diameter exceeds 25 microns, unless the droplets are moving at high velocity. The initial deposit of finely atomized sprays is several times as great as that of dusts. The loss of deposit caused by rain and wind makes the difference between dusts and atomized sprays even more pronounced in favor of the sprays.

Droplet Size as Related to Volume and Number of Drops Per Unit Area

The number of droplets of given size that would be deposited per square millimeter and per square inch (645 square millimeters) by the distribution of one gallon of spray (3,785,000,000,000,000 cubic microns) uniformly over a surface of one acre are shown in Table 1. A droplet diameter of 40 to 70 microns would result

Table 1. Size and number of droplets deposited per unit area by distributing 1 gallon of liquid uniformly over a surface of 1 acre.*

Actual diameter microns	Volume cubic microns	Number of droplets per square millimeter	Number of droplets per square inch
1	0.52	1,780,125	....
2	4.2	222,516	....
3	14.18	65,930	....
4	33.6	27,814	....
5	65.6	14,242	....
6	113.4	8,241	....
7	180	5,197	....
8	269	3,476	....
10	525	1,780	1,148,100
12	907	1,030	....
13.5	1,289	725	....
15	1,772	527	....
17.5	2,814	332	....
18	3,062	305	....
20	4,200	222	143,190
24	7,257	129	....
25	7,442	125	80,625
30	14,175	66	42,570
35	22,507	41.5	26,767
40	33,600	27.8	17,931
45	47,838	19.5	12,577
50	65,520	14.3	9,224
55	87,343	10.6	6,837
60	113,400	8.2	5,289
70	180,007	5.2	3,354
80	268,800	3.5	2,157
90	382,725	2.44	1,574
100	525,000	1.78	1,164
110	699,000	1.33	856
120	907,000	1.03	664
130	1,153,000	.81	530
140	1,440,000	.65	425
150	1,771,000	.53	347
160	2,150,000	.43	277

Actual diameter	Volume cubic microns	Number of droplets per square millimeter	Number of droplets per square inch
170	2,579,000	.36	232
180	3,061,000	.30	194
190	3,600,000	.26	168
200	4,200,000	.22	142
220	5,590,000	.17	111
240	7,257,000	.12	78
260	9,227,000	.10	65
280	11,528,000	.08	52
300	14,175,000	.066	43
400	----------------	.028	18
500	----------------	.014	9
1000	----------------	.0018	1.1

* Equivalent to 934,568 cubic microns of liquid per square millimeter.

in a deposit of 17,931 to 3,354 droplets per square inch, and a diameter of 80 to 100 microns, a deposit of 2,157 to 1,164 droplets per square inch.

For the application of concentrate sprays with air blast type ground equipment, the optimum range for diameter of droplets should be about 30 to 80 microns, with a mass average diameter of 40 to 50 microns; and for aerial application about 70 to 100 microns, both depending on the density and type of the insecticide, the volatility of the carrier, the plant growth, the kind of insect, the type of distributing device, and the atmospheric conditions. Under certain circumstances, which are discussed later, the droplet size for aerial application should be considerably greater. It will be seen in Table 1 that a slight change in diameter changes the volume and number of droplets materially. For example, when the diameter is 20 microns, there are about 8 times as many droplets as at 40 microns diameter; nearly 16 times as many at 40 microns diameter as at 100 microns; and about 125 times as many at 100 microns diameter as at 500 microns. At 50 microns diameter there are about as many droplets in one gallon of mixture as in 143 gallons when the diameter is 260 microns. In any spray pattern there are proportionately a great many more small droplets than large ones, but the greater volume of spray is in the larger droplets.

When slowly volatile or nonvolatile oils are finely atomized, the droplets on an object tend to coalesce to form a continuous film over the exposed surface. When the oil is spread evenly, approximately two gallons per acre of leaf surface is required ordinarily to form a continuous film. Better control of spider mites and such insects as thrips, aphids, and snout beetles is obtained with droplets of smaller size than are needed for large insects and gross feeders. Many first-instar aphids are only 0.6 square millimeter in size. A white pine weevil adult makes a 0.8 millimeter hole in the bark in the process of feeding, and 1,000 or more droplets of lead arsenate concentrate are required per square inch of bark to effect good control, because female weevils must be killed quickly before they lay eggs.

Small objects as legs and antennae of mosquitoes and flying insects receive a heavier deposit of small droplets than do large objects. Similarly, leaf hairs and the margins of leaves receive a heavier deposit of dusts and fine sprays than the other surfaces of leaves because of the tendency of air currents to flow around large objects. For many gross feeders a much smaller number of droplets having a diameter of 150 to 300 microns would be adequate.

Wetting agents in sprays containing water reduce the droplet volume 30 to 50 percent. Droplet size is an important factor to be considered in any studies of foliage injury. The danger of injury is lessened with a decrease in droplet size, and in the quantity of phytotoxic ingredients applied per acre. If the wetting agent is phytotoxic, it is better to use as little of it as possible and to reduce the droplet size by mechanical means.

The area of foliage *per acre* to be covered governs to a considerable extent the volume of spray required. The amount, however, is dependent also on the degree of atomization produced by the distributing apparatus. Consequently, the finer the atomization the less spray will be required to cover a given area of foliage, except if the atomization is too fine, there will be too little deposit. With less volume and finer atomization, it is necessary to increase the concentration of the spray mixture to obtain adequate dosage.

In concentrates containing water, the droplets tend to flatten out when they strike the surface of a leaf. The increase in diameter caused by spreading ranges from very little to approximately 600 percent, depending on the size of the droplet, the type and amount of wetting agent used, and the extent to which the particles dry out before reaching the foliage. Oil droplets may increase to from 10 to 15 times their original diameters, depending on the type of leaf surface, the droplet size, and the viscosity of the oil. Spreading is even greater on glass plates than on leaves.

Application of Sprays with Ground Equipment

OTHER things being equal, the distance over which blowers can drive a cloud of finely atomized spray mist is directly related to particle size. In 1940, at Gulfport, Miss., a 5-horse power blower with atomizing nozzles set in the dust-outlet tube was used to apply a fine spray of droplets 60 to 80 microns in diameter, and a coarse spray with droplets 300 to 400 microns in diameter. The finer spray was driven a horizontal distance of about 150 feet, whereas the coarser spray could be driven only 20 to 40 feet. The finer spray could have been driven vertically a distance of 40 feet with this blower. With specially designed squipment it would seem possible to drive finely atomized spray to considerably greater heights where there is no wind movement.

Under suitable conditions the blower used at Gulfport was capable of drifting a cloud of dust horizontally about 250 feet, but beyond the first 20 feet there would not have been a deposit adequate to control insects. The droplets in the fine spray mist driven by this blower, however, were deposited for a distance of fully 100 feet in sufficient quantities to give good control of insects. Recent experiments indicate that a machine of this design could be used effectively for treatment of certain broadcast crops by covering 100-foot strips, thus avoiding considerable crop damage that might be caused by usual methods of treatment.

Aerial Application of Sprays

IN the application of liquid sprays from aircraft, the size of droplets greatly affects the width of the swath covered, the distance the spray cloud will drift, the settling rate, the penetration of the ground cover, and other factors. Measurements of droplet size and width of swath were made at Whitesbog, N. J., in 1937, when an autogiro was used for applying two concentrated sprays. In these tests lead arsenate spray, with and without a wetting agent, and pyrethrum extract in kerosene were used. The spray mixtures were atomized by being spun off from rotating disks. They were applied at the rate of 3 gallons per acre.

When released 20 feet above the ground or 20 feet above the treetops, the lead arsenate spray that contained no wetting agent covered a swath 75 feet wide. The average droplet size was calculated by dividing the total deposit per given area, as found by chemical analyses, by the number of droplets. There were 215 droplets per square inch on plates placed on flat ground and 43 droplets per square inch on foliage in a sprayed woodland. The diameter of the droplets averaged approximately 240 microns. The addition of a wetting agent reduced the droplet diameter to about 200 microns and increased the width of the treated swath to 90 feet. With the pyrethrum extract-kerosene spray a swath about 100 feet wide was treated, the droplets being somewhat smaller and lighter than those in the lead arsenate spray mixture.

In aerial application the use of a larger droplet is necessitated by wind, upward air currents due to heat radiation, layers of heavy, humid air above the treetops, and small irregular areas and rugged terrain. Low flying over large areas of level terrain makes practical the use of smaller droplets, and therefore lower gallonage, at lower costs. For low flying over crops it might be practical to use average droplet sizes as small as 60 to 70 microns. Except where it is necessary to kill insects under heavy canopy, larger droplets would be preferable for the treatment of forested areas.

Droplets of high specific gravity (1.3 to 1.6) can be deposited in smaller sizes than those of lower specific gravity (0.8 to 1.0). For droplets with a specific gravity of 1.0, and of various diameters, the time required to fall 50 feet in ordinary still air at a temperature of 23°C., is as follows:

Diameter (Microns)	Time
200	13 seconds
100	51 seconds
80	1.3 minutes
50	3.4 minutes
40	5.2 minutes
20	21.0 minutes
10	1.4 hours
5	5.5 hours
1	5.0 days

Upward or downward air currents will change the rate of rise or fall, but wind velocity does not alter it (Miller, 1935, p. 160). The rate of fall of droplets of different sizes is computed by Stoke's law. Other things being equal, the smaller the droplets and the longer they float in the air, the greater the evaporation and drift. Temperature, humidity, wind velocity, and chemical characteristics also affect evaporation and drying of the particles. Considerable evaporation reduces the size of the drops and makes them fall more slowly and drift farther. Some increase in size and weight of falling particles has been obtained by the addition of Yumidol * (a hygroscopic hexahydric alcohol). Phosphorus pentoxide, magnesium chloride, and calcium chloride particles greatly increase in size and weight as they float in the air, but when mixed with an insecticide these chemicals cause injury to some kinds of foliage.

The distances that a droplet 100 microns in diameter and having a specific gravity of 1.0 would drift while falling 50 feet in air moving parallel to the ground are as follows:

Miles Per Hour	Feet
0.25	22
0.5	45
1	87
2	175
3	265
4	348
5	435
10	765

A droplet 200 microns in diameter should drift practically one-fourth and a 50 micron droplet about four times the distances given.

Liquefied Gas Aerosol Sprays

THE so-called aerosol method of application of a spray is an effective means of distributing an insecticide in droplets of small size. True aerosols are air suspensions of solid or liquid particles of ultramicroscopic size which remain suspended for long periods of hours or days. So-called aerosol sprays used as insecti-

---

*Product of Union Carbide Chemicals Co., New York cides should have a considerable proportion of larger particles ranging from 2 to 20 microns in diameter. The liquefied-gas method of producing aerosols consists in dissolving the insecticide in a low-boiling liquid such as methyl chloride, propane, or dichlorodifluoromethane (Genetron 12, Freon 12), held under pressure in metal cylinders of various sizes. When a valve is opened, the contents are ejected as a fine spray from which the propellant immediately vaporizes, leaving the less volatile ingredients suspended in the air in minute particles. A pyrethrin-sesame oil aerosol produced in this way, using Propellant 12 as the liquefied gas, for example, is extremely toxic to insect pests of the flying type in the household. Numerous other insecticides have been tested in aerosol form against greenhouse and field crop insects and the method shows promise of great possibilities in some directions.

So-called "insect bombs" are available in various sizes, from six ounces to twenty pounds. Insecticides like pyrethrum, allethrin, DDT, lindane, chlordane, methoxychlor, dieldrin, Thanite, Lethane, Strobane, TEPP, parathion, etc., are dissolved in various combinations of liquefied gas, solvents and deodorants, then held under pressure in metal containers. When released at atmospheric pressure, the propellant vaporizes, breaking up the active ingredients into fine droplets. At an average temperature of 75°F, an ordinary one-pound (one-pint) bomb or container will discharge in about 2.5 minutes, equivalent to one gallon per 20 minutes or three gallons per hour. Within limits, drop size can be increased by reducing the proportion of liquefied gas in the mixture and by increasing the orifice diameter. The chemical ingredients in the mixture must of course be compatible with the liquefied gas propellant.

In liquefied-gas aerosols the gas, such as Propellant-12 (dichlorodifluoromethane) or methylene chloride, comprises from 40 to 90 per cent of the aerosol solution. When released, the liquefied gas volatilizes quickly and the droplets immediately become smaller. Any further reduction in droplet size depends on the solvent and the volatile ingredients in the solution; therefore, the droplet diameter could be the same as in mechanically atomized sprays containing the same solvent.

For application of liquids, very small droplets, 4 to 40 microns in diameter, can be obtained by atomizing either with liquefied gas or with mechanical atomizing equipment. To deposit on the foliage the same number of droplets of given size by liquefied gas as by the mechanical method, it is necessary to apply a larger volume of liquid, the quantity depending on the proportion of liquefied gas in the solution.

Thermal Smoke Aerosols

THERMAL aerosols have a field of use for some types of enclosures and indoor treatment. They do not promise a particularly important place in field application, in spite of the spectacular appearance of smoke clouds. An expressed virtue of smokes is that they can be drifted for long distances and deposited on the wings, legs, and antennae of small insects in flight, like mosquitoes and black flies.

The main weaknesses of insecticidal smokes are as follows:

1. An extremely small percentage of the insecticide is deposited.
2. They cannot be directed against a breeze or to any desired height.
3. The intense heat required breaks down certain chemicals.
4. There is often a fire hazard and,
5. Suspensions of wettable powders usually cannot be applied.

Figure 1. Among the earliest control measures against gypsy moth is this smoke aerosol application to infested woods in Saugus, Mass., 1927.

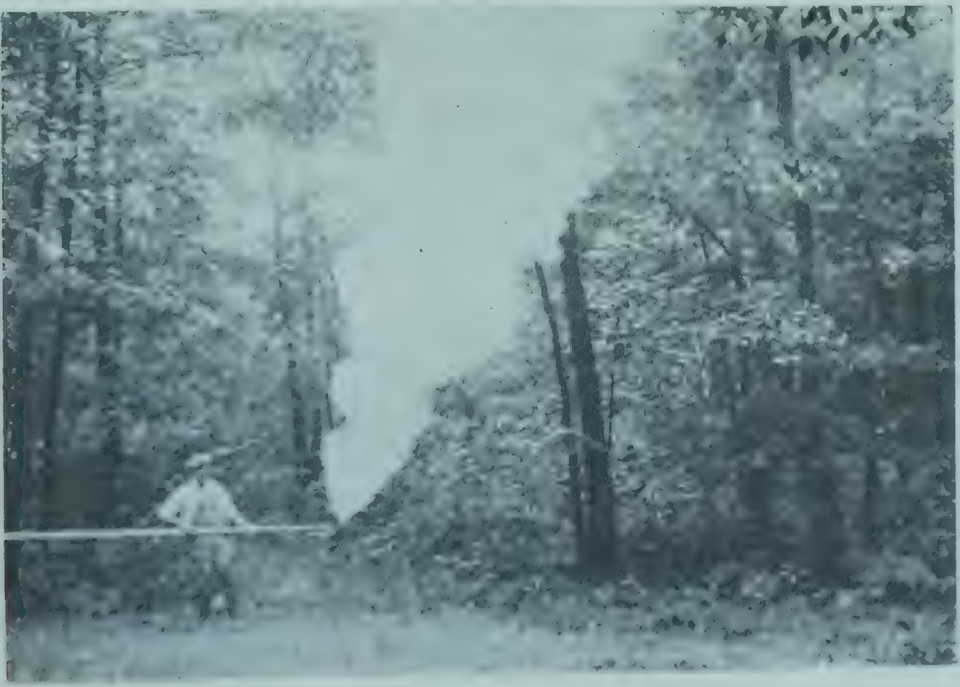


Figure 1 shows a method of applying smokes, using a combustible fuel for heat energy. Arsenicals, rotenone, pyrethrum, nicotine, and oils were applied with this method in experiments by the writer and D. F. Barnes from 1927 to 1929 under essentially all conditions. The deposit out-of-doors averaged only about two percent as great as when the same quantity of insecticide was applied by hydraulic sprayer. Efforts to increase the particle size were not very successful, because when particle size was increased enough for deposition, the particles were not projected more than a few feet from the applicator.

Since practically no particles in the smoke aerosol cloud were deposited, there was not much appreciable mortality to insects feeding on the foliage. In some cases in our tests, the insecticide broke down on account of heat. Smoke particles ranged from 0.3 to 2 microns in diameter and were not smaller than many particles of lead arsenate and calcium arsenate dust. Smokes differ from dusts, however, in that the particles in a smoke cloud move as individual, unattached particles, whereas in a dust cloud the particles often occur in groups. Individual dust particles less than 35 microns in diameter cannot be seen on slides or on foliage with the unaided eye, but groups of dust particles that are large enough can readily be seen without magnification.

Conclusions Prior to 1944

WITH the exception of some of the discussion on liquefied gas aerosols, the foregoing information was all obtained before the advent of DDT as an insecticide. It may be summarized briefly as follows:

Particle size is an important factor in determining deposit, distribution, and effectiveness of dusts and concentrated syrays. A field of resistance surrounds all objects, including plants and insects, and repels most individual dust particles of small size, as well as droplets smaller than approximately 30 microns in diameter.

Ordinary dust clouds consist of a mixture of individual particles and agglomerates of many particles attached together. If the particles are small, the deposit on insects and plants consists almost entirely of agglomerates.

Dust particles may be coated in the air by small droplets of oil, if the mixing takes place either in a vacuum or under pressure.

Liquefied gas aerosols have a field of potential use that is more restricted than for concentrated sprays, but is far greater than that for smokes.

Fine atomization is necessary to obtain adequate distribution with low gallonage, but the droplets must be large enough to deposit on foliage and insects. Apparently for ground application most of the spray should be in droplets 30 to 80 microns in diameter. For aerial application most of the droplets should be 70 to 100 microns in diameter if the areas are large and flat, and as large as 100 to 300 microns for the control of certain forest insects on rugged terrain.

Tables 2, 3 and 4 on pages 31 and 33 contain data on spray deposits resulting from applications at different pressures, varying distances from the wall surface, etc. Although not compared in the tables, it is interesting to note that smoke aerosols give a very low residual deposit.

Some factors affecting particle or droplet size are: type of distributing device, pressure, nozzle design, orifice size and shape, air velocity, spray concentration, density, type of insecticide, surface tension, viscosity of the mixture, rate of volatilization of the ingredients, distance to which the particles must be drifted, wind and other meteorological factors, volume, and compactness of foliage, and settling rate.

Characteristics of Spray Atomization and Deposit

INSECTICIDE sprays may be applied either as finely atomized *space* sprays which float in the air, or as less finely atomized sprays for *residual* deposit and effect, or as a combination of both. It is hazardous to breathe the more toxic insecticides as space sprays. However, insects may be controlled by applying small quantities of these toxic insecticides as residual sprays with equipment that produces a wide-angle, low volume spray. This requires the selection and use of correct equipment and methods of applying such sprays. The importance may be pointed up by citing a few cases. In testing liquefied gas dispensers it was found that only 20 to 40 per cent of the insecticide deposited on a vertical wall at 12 inches from the dispenser, and at 24 inches only 3 to 15 per cent of it deposited. The remaining portion was made up of small particles and drifted off in the air. It could settle on food stuffs or be inhaled. This was true in spite of the fact that the liquefied gas aerosol industry is a multi-million dollar business annually. Aerosols have had the benefit of heavily financed research programs and skillful and extensive promotion. This boosted sales to about 300 million small units in 1956.

In general, the same low deposit ratio occurs when compressed-air spray guns are used to apply insecticide and paints. The paint spraying industry is also a multi-million dollar business. Millions of acres of crops and pastures are now being sprayed annually with low gallonage concentrate rigs. The atomization, spray angle and width and distance of spray projection by the nozzles are factors that greatly affect the result. Incorrect setting of the nozzles on booms and cultivators can easily reduce the deposit by 20 to 40 percent.

To obtain the best deposit, the equipment should atomize the liquid to the correct size and release it with sufficient velocity to deposit as many as possible of the droplets on the sprayed surface. The application apparatus should be selected on the basis of its ability to deliver the desired amount of spray and deposit it uniformly and to the greatest degree on the surface being treated. Rate of delivery for a given deposit depends on several factors including:

1. The concentration of the insecticide in the formulation.
2. The amount of spray that fails to deposit on surfaces to be treated including upper and lower leaf surfaces; vertical and horizontal surfaces such as ceilings and shelves.
3. Speed of movement of the spray outlet parallel to the surfaces being sprayed, and,
4. The swath width.

Degree of atomization depends both on the amount of energy and its efficiency of application in relation to the quantity (or rate of output) of liquid and its physical characteristics. In compressed air, steam, and mist blower atomizers, the energy is supplied by a moving air or gas coming in contact with a relatively stationary liquid. The friction between the two draws the liquid out in filaments in which unstable waves are formed, which then collapse into droplets. Atomization is greatest when the greatest number and amount of forces and contortion effects are applied to the liquid in the shortest period of time. After the liquid assumes the shape of a sphere, it is more difficult to break up. In liquid-pressure atomizers, including the liquefied gas type, the friction between a moving liquid and a relatively stationary gas results in droplet formation.

To deposit on a surface, spray droplets must have sufficient momentum not only to carry them the required distance, but also to enable them to penetrate the air stream carrying them when it is deflected by the surface. All sprays, including the solid stream type, generate an air stream that moves with the droplets. Momentum of droplets increases with either their size or velocity, or both. Small droplets must move fast enough to have sufficient momentum to penetrate the air cushion formed when the stream is deflected in front of objects. Since their velocity decreases rapidly with the distance from the nozzle, it is important that the spraying distance be kept well within the limits in which the droplets have sufficient momentum to deposit. The author has conducted many tests to determine the distance to which sprays will project and deposit with and without wind movement and with various rates of travel of the spray machine or nozzle.

Yeomans and Rogers (1953) state that the distance to which a droplet can penetrate still air can be computed by the formula:

$$S = \frac{d^2 p V}{18 N}$$

"where

S = stopping distance, in centimeters.
d = diameter of droplet, in centimeters.
p = density of droplet, in grams per cubic centimeter.
V = Velocity of droplet, in centimeters per second.
N = Viscosity of air, in poises.

"Hence, if a droplet 10 microns in diameter is projected at a velocity of 5,000 centimeters (equivalent to 112 m.p.h.) per second into still air, the viscosity of which is 1.8 x 10^{-4} poises, it will penetrate 1.54 centimeters. A droplet 50 microns in diameter will penetrate 38.6 centimeters and a 100-micron droplet, 1.54 meters."

In other words, for each mile per hour the droplet is moving it will project 0.01373, 0.344, and 1.373 centimeters for droplets of 10, 50 and 100 microns, respectively.

Table 2 lists calculations made by the author on the distance to which droplets of given size and velocity can penetrate still air. It supplements the work of Yeomans and Rogers (1953).

In tests conducted from 1930 to 1935, Potts concluded that the spraying distance is increased with a reduction in the included spray angle and with increase in liquid output. The type of spray—whether flat, hollow cone, or solid cone—does not seem to influence the deposit greatly. Pressure does not necessarily control the distance to which the spray will throw. For example, when the nozzle pressure of solid-stream sprayers with nozzle orifices (tips) of ¼ to 5/16 inch was increased from 300 p.s.i. to 900 p.s.i., there was only a 15 per cent increase in spraying height. On the other hand, increasing the orifice from ⅛ inch to ¼ inch increased the distance of throw 90 per cent at 500 p.s.i. Moreover, in atomizing nozzles with small orifices of 1/50 to 1/20-inch diameter, the distance of spray projection was increased only a fraction by pushing

Table 2. Distance to which droplets of given size and velocity can penetrate still air.

Diameter of droplet (microns)	Velocity in m.p.h.	Distance projected in		Diameter of droplet (microns)	Velocity in m.p.h.	Distance projected in	
		centimeters	inches			centimeters	inches
10	1	.01373	.0054	100	1	1.373	0.54
	5	.0687	.027		5	6.87	2.7
	25	.3433	.135		25	34.33	13.5
	50	.6866	.27		50	68.66	27.
	100	1.3732	.54		100	137.32	54.
	150	2.06	.811		150	206.	81.1
	200	2.74	1.07		200	274.	107.
25	1	.0858	.0338	150	1	2.089	.823
	5	.429	.169		5	10.445	4.115
	25	2.145	.845		25	52.225	20.57
	50	4.29	1.69		50	104.45	41.15
	100	8.58	3.38		100	208.9	82.3
	150	12.87	5.07		150	313.3	123.
	200	17.16	6.76		200	417.8	164.
50	1	0.344	.135	200	1	5.492	2.16
	5	1.72	.677		5	27.46	10.8
	25	8.6	3.38		25	137.3	54.
	50	17.2	6.76		50	274.6	108.
	100	34.4	13.5		100	549.2	216.
	150	51.6	20.3		150	823.8	324.
	200	68.8	27.1		200	1098.	432.

up the pressure from 50 p.s.i. to 400 p.s.i., but the spray deposit was noticeably decreased, due to the droplets being *smaller* and to a slight increase in angle of spread.

In Yeomans and Rogers (1953) the accompanying tables were presented. Table 3 gives deposit measurements on a vertical wall surface when released at different distances from a stationary liquid-pressure atomizing nozzle, while Table 4 gives some spray deposits on a vertical wall surface.

Compressed air atomizing systems are featured by (1) a low volume of high velocity air, (2) a medium to low rate of liquid output and (3) medium to low pressure on the liquid. Increasing the pressure on the liquid, or increasing the nozzle's orifice diameter, increases the drop size.

In compressed air atomizer types, the combination of low liquid pressure of 0 to 10 p.s.i., high air pressure, and small orifices is capable of producing finely atomized droplets or aerosols in the 5 to 25 micron range. This type machine has a place for use in buildings and greenhouses, but for out-of-door application it cannot penetrate the foliage or drive the spray far enough. It is also more complicated and usually more expensive than either the direct liquid pressure or the mist blower types.

Deposits can often be increased as much as 15 per cent by changing from a smooth surface to a rough surface, as by changing from a smooth metal facing to soft paper.

Adequate respirators should be worn by operators when fine sprays are being used, and suitable coverings should be placed over surfaces not to be contaminated. Particles in this size range are usually not visible in the air or on the surface on which they settle, since the smallest diameter that can be seen with the naked eye is about 35 microns. Yeomans and van Leeuwen (1954) give deposit data from three nozzles selected to demonstrate the results from high-, medium-, and low-output nozzles. The liquid used in these tests was either water or a No. 3 burning oil (Texaco 300).

Figure 2 shows the per cent of spray deposited at various distances from the metal wall surface when a high-output nozzle (Spraying Systems D3-25 *) was used. This is a disk-type nozzle producing a hollow-cone spray, the spray angle of which is 68° when operated at 100 pounds pressure. At this pressure, the output of water was 0.29 gallons and of the burning oil 0.39 gallons per minute.

---

*Spraying Systems Co., Bellwood, Ill.

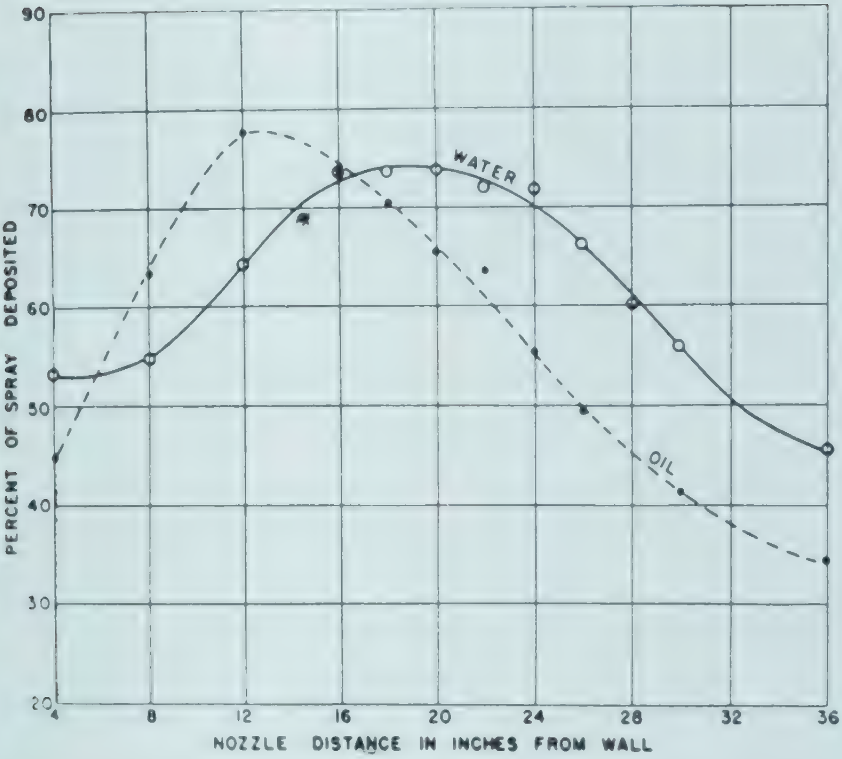


Figure 2. Above, per cent of spray deposited at various distances from a metal wall surface when using nozzle D3-25 of Spray Systems Co. at 100 psi.

Figure 3. Below, using Spraying System's "Teejet" nozzle 50015 at 50 psi.

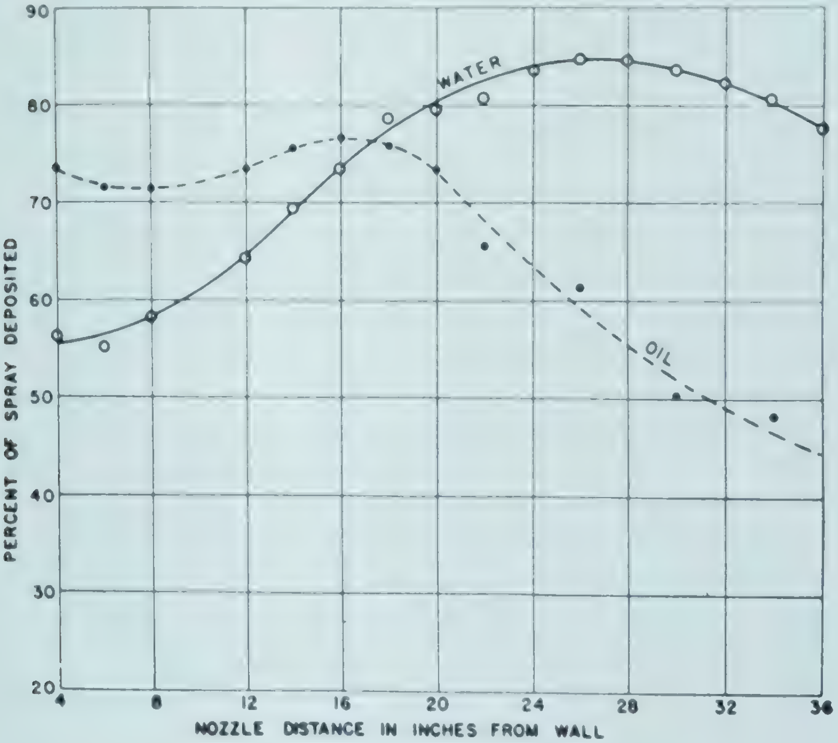


Table 3. Spray deposits on a vertical wall surface when released at different distances from a stationary liquid-pressure atomizing nozzle*.

Pressure p.s.i.	Output per minute	Spray angle	Droplet diameter		Deposit at indicated distance from surface		
			mass median	maximum	inches		
					24	18	12
	gallons	degrees	microns	microns	percent	percent	percent
			Flat sprays				
100	0.24	60	146	240	72	77	83
100	0.16	90	92	210	60	66	80
100	0.062	90	38	140	48	61	80
50	0.165	52	177	300	73	80	82
50	0.11	82	108	210	57	75	83
50	0.044	77	92	220	46	66	82
			Hollow-cone sprays				
100	0.033	71	80	190	31	44	66
100	0.29	68	140	270	65	84	90
50	0.023	57	85	300	40	60	79
50	0.21	63	160	270	63	82	91

*From Yeomans and Rogers (1953)

Table 4. Spray deposits on a vertical surface when released at different distances from a stationary compressed air-atomizing nozzle*.

Pressure (p.s.i.)		Drop Diameter		Percent Deposit at indicated distance from surface.		
air	liquid	Mass median	Max-imum	24 inches	18 inches	12 inches
		microns	microns			
10	0	50	150	65	75	83
30	0	35	70	46	60	70
70	0	20	50	30	33	38
15	5	150	500	80	83	86
20	5	85	250	59	71	81

*From Yeomans and Rogers (1955).

Using oil with the spray the particle size was as follows:

Diameter	Accumulative Percent
30	1.5
100	36
150	56
200	70
270	100

Mass median diameter = 140 microns.

This nozzle produced a spray the deposit of which decreased considerably when the nozzle was closer than 10 inches. The most efficient distance with oil was 12 inches, where about 78 percent of the spray deposited. The spray that did not deposit had particles ranging up to 200 microns in diameter, but most of them were smaller than 75 microns.

In a room 16 by 16 feet, with a ceiling at eight feet, and the nozzle held 12 inches from the wall and six feet from the floor, all of the deflected particles larger than 30 microns in diameter fell to the floor within three feet of the wall. Smaller particles dispersed and settled fairly evenly over the entire floor; they represented about 1.2 percent of the spray, compared with 1.5 percent found in the original spray.

Figure 3 shows the results of a medium-output nozzle (Spraying Systems "Teejet" 50015), a flat-spray nozzle, with a spray angle of 53° when operated at 50 pounds pressure. The output at this pressure was 0.1555 gallon per minute with water and 0.17 gallon with oil. The particle size with the oil spray was as follows:

Diameter	Accumulative Percent
30	1
100	14
150	35
200	60
300	100

Mass median diameter = 180 microns.

This nozzle deposited a high percentage of the spray over a wide range of distances and was considered an excellent nozzle for residual spraying. The low percentage of particles 30 microns in diameter or smaller would minimize the health hazard from drifting.

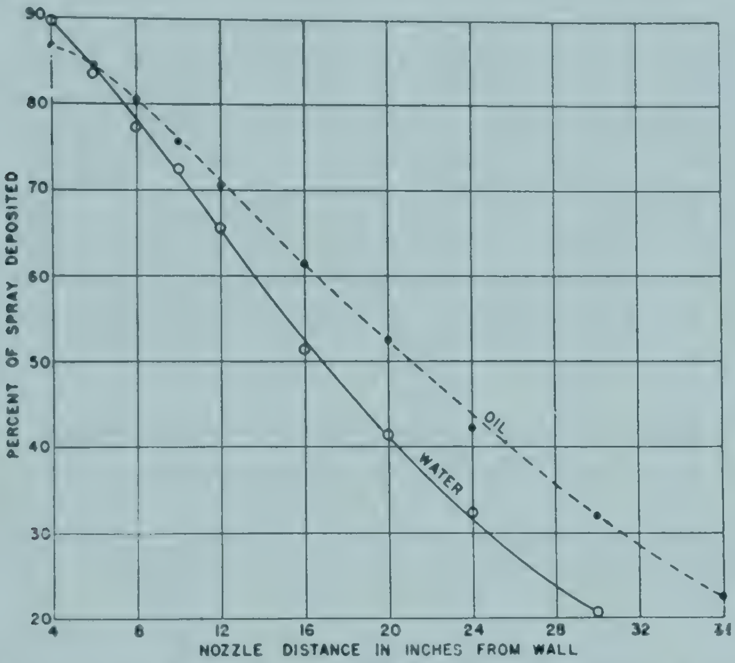


Figure 4. Per cent of spray deposited at various distances from a metal wall surface, using Spraying System's nozzle "Teejet" 1.5 at 100 psi.

Figure 4 shows the percentage of deposit from a low-output nozzle (Spraying Systems "Teejet" 1.5), a hollow-cone spray nozzle. When operated at 100 pounds pressure the output was 0.037 gallons per minute with water and 0.054 gallons with oil. The spray angle is 70° at this pressure. The particle size with the oil spray was as follows:

Diameter	Accumulative Percent
30	15
200	100

Mass median diameter = 100 microns.

This nozzle was considered unsuitable for spraying a wall at a distance greater than 12 inches. The large proportion of particles smaller than 30 microns would create a considerable health hazard from drifting.

The deposit from these nozzles did not change much when the pressure was varied between 50 and 100 pounds per square inch.

This was due apparently to the increase of particle size and decrease of spray angle with lowering pressure to compensate for the lowering of velocity and output with pressure. As mentioned before, an increase in deposit of as much as 15 percent would occur on a relatively rough surface compared with our smooth-metal test surface. Spraying upward to a ceiling would require a decrease in spraying distance to obtain the same deposit as on a wall surface.

These studies demonstrate that within the range of nozzles tested, as much as 15 per cent or more of the spray is not deposited on the surfaces being sprayed. The portion not deposited consists of particles 30 microns or smaller, which contaminate the air in the vicinity. When highly toxic concentrated insecticidal formulations are being used, this could constitute a definite health hazard.

Table 5. Output of cone and solid stream type nozzles for given orifice diameters and pressures.

Orifice diameter in hundredths of an inch	Output as a solid stream at 50 p.s.i.	Output as 70 to 80° cone* spray at:**		
		25 p.s.i.	50 p.s.i.	100 p.s.i.
	g.p.h.	g.p.h.	g.p.h.	g.p.h.
1	1.1	....	....	.5
2	4.4	1.0	1.45	2.1
3	9.9	2.3	3.24	4.6
4	17.6	4.1	5.76	8.1
5	27.5	6.3	9.0	12.6
6	40.	9.1	13.0	18.3
7	54.	12.6	18.	25.3
7.8	66.	15.4	22.	30.8
8	70.4	16.1	23.	32.2
9	89.1	20.5	29.3	42.
10	110.	25.3	36.3	51.8
12.5	172.	39.2	56.	78.5
15	248.	57.	81.	114.
17.5	337.	77.	110.	154.
20	484.	101.	144.	202.
25	688.	158.	225.	315.
37.5	1547.	355.	506.	709.
50	2750.	630.	900.	1260.

* At outputs below 3 G.P.H. the included angle was less than 80 degrees, depending somewhat on pressure.

** Divide by 60 to find the G.P.M.

The studies, therefore, show the necessity of testing each type of nozzle to determine not only the percentage of the spray 30 microns in diameter and smaller, but also the efficient spraying distance for each formulation. In many cases such a test will show that a nozzle is unsuitable for wall spraying.

Nozzle Delivery as Related to Orifice Type. The data given in the text and tables that follow are from hundreds of tests, replicates and thousands of samples and droplet measurements made in an intensive and extensive study of this subject during each of the past 10 years. The data and information presented are that of the author except when indicated otherwise.

Table 5 lists the water output of cone and solid-stream nozzles for given orifice diameters and pressures. The correct use and setting of these nozzles will be given later under equipment construction and use. It is important to note that atomizing cone-type nozzles with 80° included angle deliver only 30 to 40 per cent as much liquid as solid-stream orifices of the same diameter and pressure. The output decreases as the angle of spread is in-

Table 6. Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 25 p.s.i. using 32 seconds viscosity oil.

Nozzle No.	Orifice diameter in hundredths of an inch	Output per hour*	Spray angle	Droplet diameter: Numerical average diameter	Droplet diameter: Mass average diameter	Droplet diameter: Maximum
		gallons	degrees	microns	microns	microns
2	2	1.0	70	78	98	200
3	3	2.3	70	96	122	224
4	4	4.1	80	110	143	248
5	5	6.3	80	132	175	274
6	6	9.1	80	150	208	286
7	7	12.6	80	210	272	294
8	7.8	15.4	80	220	285	380
9	8	16.1	80	230	302	430
10	9	20.5	80	238	304	444
11	10	25.3	80	250	325	500
12	12.5	39.2	80	272	350	560
13	15	57.	80	330	420	580
14	17.5	77.	80	360	468	620

* Divide by 60 to find gallons per-minute.

creased from 0 to 180 degrees. The flat or fan-type nozzles deliver theoretically the same output as the solid stream orifices. Actually, most of them deliver about 10 per cent less liquid than solid-stream orifices due to resistance from the restricting walls of the nozzle tip located just beyond the orifice. In general, rate of output increases or decreases as the square root of the pressure. For example, a given orifice delivered 5, 7.07, and 10 gallons per hour at 25, 50, and 100 p.s.i.

Viscosity and surface tension are sometimes factors in the output of liquid as related to temperature. For example, at room temperature the output of five direct pressure nozzles ranged from 5 to 12 per cent greater than for water when applying kerosene and oils of 30 to 35 seconds Saybolt viscosity. At 40 seconds viscosity the flow of the water and oils was equal. At 50 seconds viscosity, the rate of flow of oils was 85 per cent as fast as for water, and at 100 seconds viscosity the oils would not flow properly through orifices smaller than 3/32 inch. However, when made up as 25 per cent oil emulsions, oils of 100 to 200 seconds viscosity

Table 7. Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 50 p.s.i.

Nozzle No.	Orifice diameter in hundredths of an inch	Output per hour at 50 p.s.i.*	Spray angle	Droplet diameter		
				Numerical average diameter	Mass average diameter	Maximum
		gallons	degrees	microns	microns	microns
2	2	1.45	72	65	83	170
3	3	3.24	72	83	108	200
4	4	5.76	80	85	111	222
5	5	9.0	80	122	159	250
6	6	13.0	80	132	172	268
7	7	18.0	80	160	200	280
8	7.8	22.	80	180	238	332
9	8	23.	80	210	255	390
10	9	29.3	80	222	280	400
11	10	36.3	80	224	296	428
12	12.5	56.	80	248	327	450
13	15	81.	80	265	340	480
14	17.5	110.	80	305	395	515

* Divide by 60 to find gallons per-minute.

flowed at about the same rate as water. At temperatures of 30°F. or lower, oils of 60 seconds viscosity or greater would not flow properly through nozzles.

ATOMIZATION OF CONE-TYPE NOZZLES AT DIFFERENT PRESSURES. Tables 6, 7, and 8, give the average and maximum drop sizes produced at 25, 50 and 100 pounds pressure by 13 different nozzles having an orifice diameter range of 0.02 to 0.175 inch. In most cases the spray angle was 80 degrees. The data show that the drop size increases rapidly with increase in orifice diameter, whereas, it decreases to a much lesser degree with an increase in pressure (see Tables 6, 7, and 8).

ATOMIZATION, USING FLAT SPRAY NOZZLES WITH AND WITHOUT AN AIR BLAST. Table 9 presents atomization data from a series of flat spray nozzles. Columns 3, 4, and 5 list the mass average drop diameter for pressures of 25, 50, and 100 p.s.i., when the nozzles were not in an air blast. Column 6 lists the drop size when the nozzles were fixed on the spray ring of a 12-inch diameter air

Table 8. Spray atomization of a range of liquid-pressure, cone type atomizing nozzles at 100 p.s.i.

Nozzle No.	Orifice diameter in hundredths of an inch	Output per hour*	Spray angle	Droplet diameter		
				Numerical average diameter	Mass average diameter	Maximum
		gallons	degrees	microns	microns	microns
1	1	0.5	65	52	58	120
2	2	2.1	70	60	76	160
3	3	4.6	70	76	88	170
4	4	8.1	80	80	100	190
5	5	12.6	80	113	135	222
6	6	18.3	80	122	148	242
7	7	25.3	80	172	225	275
8	7.8	30.8	80	197	230	285
9	8	32.2	80	192	232	298
10	9	42.	80	198	235	325
11	10	51.8	80	205	245	340
12	12.5	78.5	80	210	255	394
13	15	114.	80	240	295	398
14	17.5	154.	80	282	335	420

* Divide by 60 to find gallons per-minute.

outlet with the air moving at 125 m.p.h. The nozzles were in the air stream and pointing at right angles to it.

The atomization by flat nozzles is not quite as fine nor as uniform as for cone nozzles at comparable outputs. The air blast breaks up the larger drops and reduces the wide range in drop sizes produced by the various nozzles having different spray delivery rates.

A characteristic of most fan nozzles is their tendency to throw the larger drops (sometimes called "horns") to the two opposite edges of the spray "fan." In such nozzles the average drop size is smaller in the center of the fan directly in front of the orifice. Also, some fan-type nozzles deliver more spray towards the ends of the spray fan than towards its center and vice versa. For example, in the same period of time a nozzle delivered 100, 90, 115, 150, and 105 ml. of spray at 0, 3, 6, 9, and 12 inches from the center of the spray fan.

Atomization as affected by various combinations of nozzles, pressures, and air volumes and velocities. Table 10 shows the drop size produced by air velocities of 85-90, 125, and

Table 9. Atomization of flat spray nozzles without an air blast and at right angles to an air blast of 125 m.p.h. in a 12 inch diameter outlet.

Orifice diameter in hundredths of an inch	g.p.h. at 50 p.s.i.	Mass average drop diameter out of air blast			Mass average diameter in 125 m.p.h. air blast at 50 p.s.i.
		25 p.s.i.	50 p.s.i.	100 p.s.i.	
		microns	microns	microns	microns
1	1	......	85	70	36
2	4	160	122	82	40
3	9	175	145	122	43
4	17	185	160	137	46
5	25	190	172	155	52
6	37	220	196	172	54
7	50	235	216	182	58
8	65	245	215	200	60
9	80	260	230	215	63
10	100	340	235	215	65
12.5	160	365	345	300	70
15	225	385	360	325	75
17.5	300	455	435	375	85

Table 10. Atomization produced by given air velocities at given pressures using a 12-inch diameter air outlet with nozzles pointing at right angles to air blast.

Orifice diameter in hundredths of an inch	Drop diameter in air blast at given pressure:					
	25 p.s.i.		50 p.s.i.		100 p.s.i.	
	Mass average diameter	Maximum	Mass average diameter	Maximum	Mass average diameter	Maximum
	microns	microns	microns	microns	microns	microns
	Air velocity: 85-90 m.p.h.					
2	70	160	64	150	58	146
3	75	175	70	167	62	150
4	78	175	72	166	67	155
5	83	190	76	170	69	160
6	83	190	78	176	70	165
7	88	200	82	188	76	180
8	88	210	83	190	80	180
9	94	220	87	200	83	186
10	106	230	94	212	88	206
12.5	125	240	115	218	95	210
15	134	255	117	224	100	215
17.5	140	270	126	235	115	225
	Air velocity: 125 m.p.h.					
2	40	140	34	140	32	130
3	42	145	36	150	32	126
4	44	152	40	155	36	140
5	47	160	43	155	36	144
6	50	170	43	162	40	150
7	52	172	46	164	45	156
8	56	176	48	164	46	154
9	58	180	50	170	46	164
10	62	185	56	173	50	164
12.5	75	190	65	180	52	167
15	83	195	70	185	65	170
17.5	88	200	75	185	70	170

Table 10 (Continued)

Orifice diameter in hundredths of an inch	Drop diameter in air blast at given pressure:					
	25 p.s.i.		50 p.s.i.		100 p.s.i.	
	Mass average diameter	Maximum	Mass average diameter	Maximum	Mass average diameter	Maximum
	microns	microns	microns	microns	microns	microns
	Air velocity: 150 m.p.h.					
2	32	125	30	115	26	110
3	35	125	30	120	28	113
4	38	130	32	120	30	115
5	40	133	36	127	32	120
6	42	136	36	130	33	120
7	44	140	38	133	35	127
8	46	143	40	135	37	135
9	46	145	44	140	38	130
10	50	150	43	145	40	133
12.5	55	155	47	150	42	140
15	55	160	50	160	45	150
17.5	58	175	55	170	50	160

150 m.p.h. respectively, using liquid pressures of 25, 50, and 100 p.s.i. The nozzles are of the atomizing cone type and were on a ring of four nozzles inside the air blast at the mouth of the outlet and were pointing at right angles to the direction of the air flow. Atomization or degree of fineness of the spray, increases with increase in air velocity and liquid pressure and with decrease in orifice size. Air velocity had a greater effect on drop size than liquid pressure or orifice size.

Air velocities in feet per minute and miles per hour for given inches-of-water air pressure from blowers are given in Table 11.

$$\text{Velocity (mph)} = 4005\sqrt{\text{inches of water}} \times \frac{60}{5280}$$

$$\text{Cubic feet per minute} = 4005\sqrt{\text{inches of water}}\ \frac{\times\ \Pi r^2 \times 12}{1728}$$

When reading columns of kerosene or equivalent, multiply the result by 0.9 to find inches of water pressure.

Table 12 shows the degree of atomization when using different sizes of whirljet nozzles at 40 p.s.i. with the nozzles pointing in various positions in relation to the direction of the air blast. When a B 5 nozzle was pointed respectively at right angles to the air stream, against it, and with it, the mass average drop diameter was 58, 52, and 75 microns, respectively. The finest atomization results when the spray is ejected against the air blast. In small air outlets this is not always practical if the spray should strike the walls of the outlet. When this B 5 nozzle was placed 1½ inches outside the air blast while pointing at right angles to it the drop size was increased from 58 microns to 65 microns. This indicates the effect of placing the nozzle inside the air blast as compared with outside.

Table 11. Air velocities for given air pressures in inches of water.

Air pressure in inches of water*	Air velocity in		Air pressure in inches of water	Air velocity in	
	feet per minute	m.p.h.		feet per minute	m.p.h.
0.5	895	35.	11.5	13,581	154.2
1.0	4,005	45.	12.	13,873	157.3
1.5	4,886	55.5	12.5	14,159	160.8
2.0	5,661	64.2	13.	14,440	163.8
3.0	6,928	69.3	13.5	14,715	167.2
3.5	7,489	84.6	14.	14,985	170.4
4.0	8,010	90.6	15.	15,500	176.
4.5	8,495	96.6	16.	16,020	182.
5.0	8,955	102.	17.	16,513	188.
5.5	9,392	106.8	18.	16,981	193.
6.0	9,810	111.6	19.	17,422	198.
6.5	10,210	115.8	20.	17,902	204.
7.0	10,596	120.6	25.	20,025	228.
7.5	10,968	124.8	30.	21,930	250.
8.0	11,327	128.4	36.	24,030	275.
8.5	11,676	132.6	......	....	....
9.0	12,015	136.2	......	....	....
9.5	12,344	139.8	......	....	....
10.0	12,644	144.	......	....	....
10.5	12,977	147.	......	....	....
11.0	13,283	150.6	......	....	....

* When reading the velocity for given pressures on kerosene (or other light oils of equivalent sp. gr. and viscosity) multiply the figures in column by 1.12 to account for the difference in pressure required to lift water as compared to the oil.

In measuring the atomizing effect of a liquid moving with the air blast, multiply the speed in m.p.h. of the liquid at the nozzle by 0.7 and subtract it from the speed in m.p.h of the air. For example, if the liquid leaves the nozzle at 50 m.p.h. with an air blast of 125 m.p.h. the effect is that of a (125 — 50 X .7) 90 m.p.h. air stream. If the spray leaves the nozzle at 50 m.p.h. against a 125 m.p.h. air stream the atomizing effect is equal to that of a 160 m.p.h. air stream (50 X 0.7 + 12.5).

Atomization by Hand Atomizers. Hand atomizers have many of the characteristics of compressed air sprayers, aerosol "bombs," and high velocity mist blowers. They came into use for applying conventional dilute sprays, a purpose for which they are very poorly suited because of the long time required to spray even a small volume. For example, over seven days, several hand atomizers would be required to apply 150 gallons of conventional spray mixture to an acre of plants, because of the short life of hand atomizers and the slow rate of liquid delivery. On the other hand, the writer has treated two acres with a hand atomizer in one day when applying concentrated spray at the rate of 2 to 5 gallons per acre. This does not mean that the hand atomizer has a place for treating large areas of crops. However, the use of concentrates does greatly extend the potential field of application of hand atomizers. Produc-

Table 12. Atomization of spray from whirljet nozzles ejected at 40 p.s.i. from given directions in a 12-inch diameter outlet with the air stream moving at 125 m.p.h.

Whirljet nozzle No.	Diameter of orifice (inch)	g.p.h.* at 40 p.s.i.	Drop diameter out of air blast	Mass average drop diameter with nozzles pointing		
				at right angles to air blast	against air blast in center of outlet	with the air blast
			microns	microns	microns	microns
B1	1/16 (.062)	12	225	48	40	53
B2	5/64 (.078)	24	260	52	44	57
B3	3/32 (.093)	36	290	55	48	60
B5	1/8 (.125)	60	325	58	52	75
B10	3/16 (.187)	120	405	65	58	78
B15	7/32 (.218)	180	425	77	62	85

* Rating for water.

tion and sales for the past five years indicate that over 10 million dollars worth of hand atomizers are being produced yearly, representing 30 to 40 million units. Most of these sprayers go to home owners and owners of livestock, barns, camps, restaurants, and other small buildings.

Most people do not yet know that hand atomizers can be used for applying concentrated sprays. Even fewer people know how to select and operate them or what mixtures and dosages to use. The method of construction and use of hand atomizers is discussed under the construction and operation of equipment (Chapter III).

Table 14 shows the degree of atomization produced with combinations of air and liquid orifices of different diameters. Hand

Table 13 showing atomization of spray ejected at 40 p.s.i. from two whirljet nozzles at right angles to the air blast of air outlets of different diameter.

Air outlet diameter inches	Whirljet nozzle No.	Mass average droplet diameter for air velocities of:			
		m.p.h. 80-95	m.p.h. 125	m.p.h. 150	m.p.h. 200
2	B1	93	65	61	51
	B3	135	83	73	57
4	B1	87	58	52	44
	B3	120	67	56	42
8	B1	83	54	40	38
	B3	115	58	50	42
10	B1	78	52	38	38
	B3	110	57	49	40
12	B1	76	47	38	34
	B3	95	55	48	38
24	B1	60	44	36	30
	B3	70	48	38	34

Table 13 above shows that the average drop diameter decreases with increase in diameter of outlet. This is due to the fact that air velocity decreases less rapidly after it leaves large outlets than is the case for small outlets. The spray was delivered at 40 P.S.I.

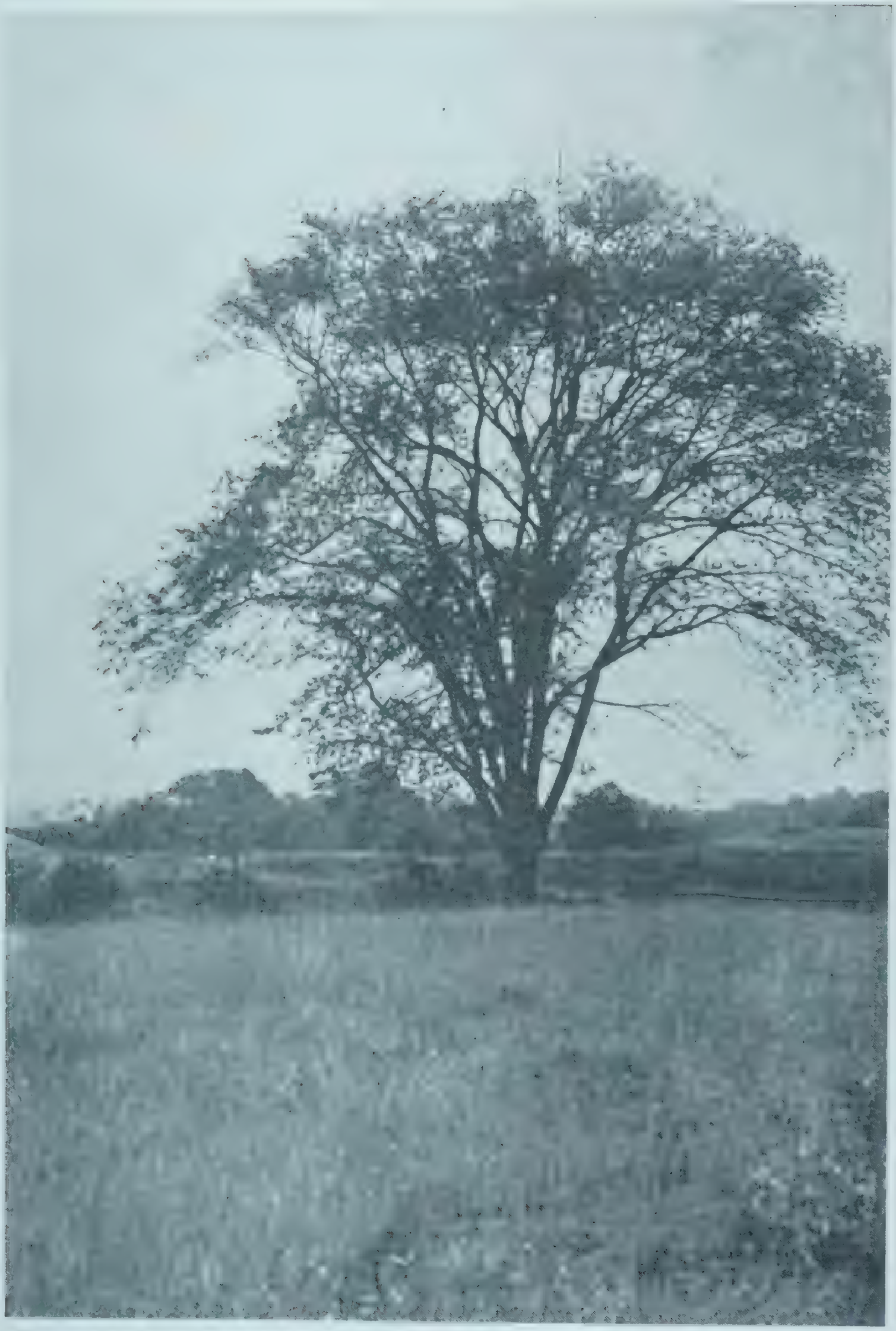


Figure 5. A pulley and two-way rope suspended 10 feet above the top of a 70 foot elm tree. A group of slide holders are attached at 5-foot intervals along one length of the rope from the ground to the pulley. The picture was taken in October after half of the leaves had fallen.

atomizers operate at a higher air velocity (2 to 5 pounds pressure, or about 350 to 460 m.p.h. velocity) than mist blowers. This velocity is lower than for compressed air sprayers which may operate at 10 to 100 p.s.i. In testing the orifice combinations in the following table, the two orifices were adjusted to the position that gave the best atomization. In trying to select hand atomizers on the market it was discovered that only about 40 per cent had the two orifices in correct adjustment. Over 100 hand atomizers of all known makes were examined, the drop samples being recovered in a settling chamber.

The data show that with a given pressure, atomization increases with reduction in size of liquid orifice and with increase in size of air orifice. In these calibration studies, the height of the liquid when not spraying was two inches below the orifice. When spraying, the

Table 14, showing atomization produced by different air and liquid orifice size combinations.

Diameter of air orifice	Diameter of liquid orifice	Mass average droplet diameter
inch	inch	microns
1/32	1/64	16
	1/32	20
	3/64	30
	1/16	38
	3/32	46
	1/8	60
1/16	1/64	14
	1/32	17
	3/64	26
	1/16	34
	3/32	36
	1/8	46
	1/64	10
	1/32	15
3/32	3/64	23
	1/16	27
	3/32	34
	1/8	44
	5/16	62
1/8	1/16	12
	1/32	13
	3/64	20
	1/16	26
	3/32	30
	1/8	38
	1/4	54[a]
5/16	5/16	50[b]

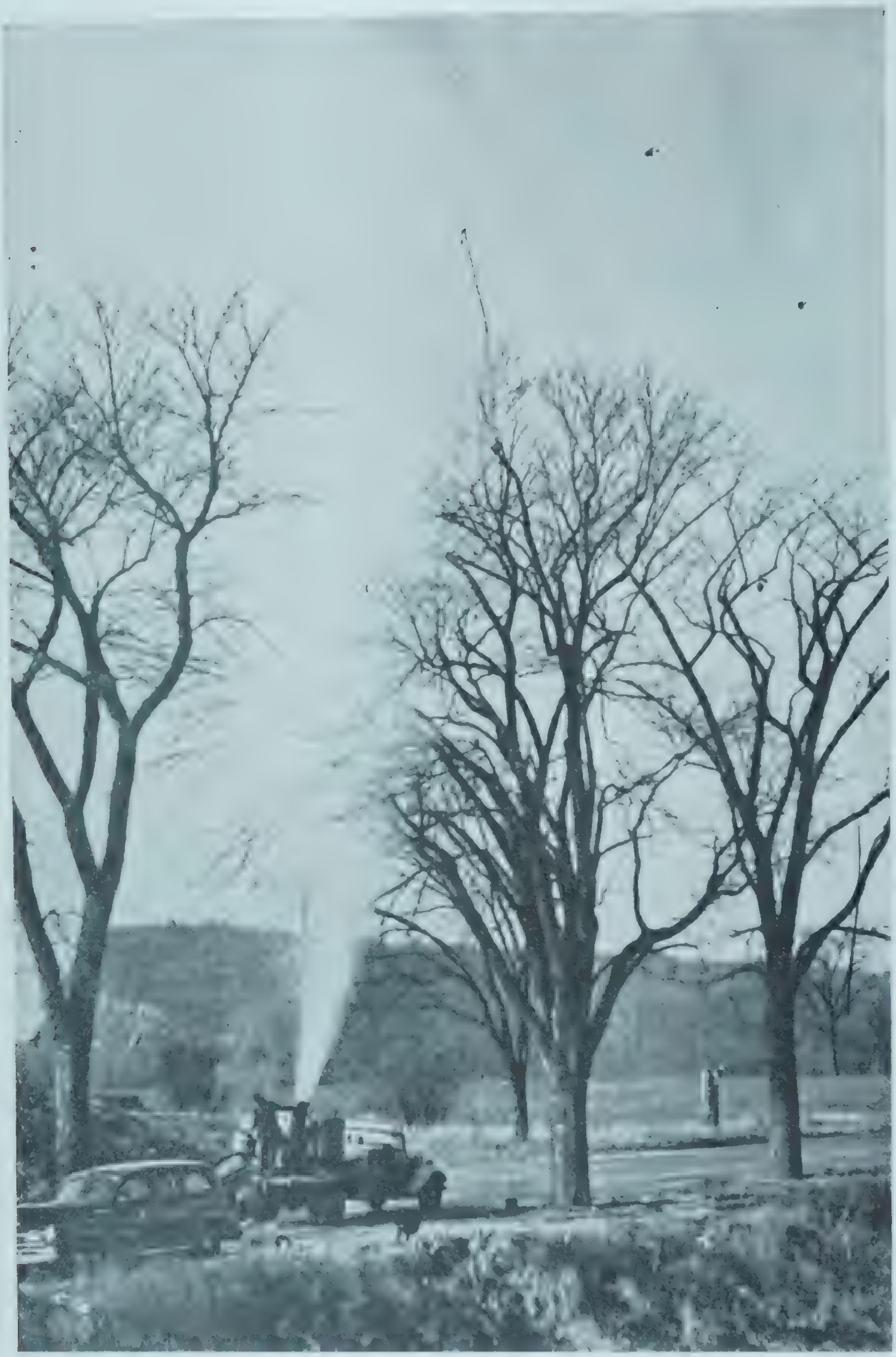


Figure 6. Truck mounted mist blower spraying a 70-foot elm in the dormant season, with dust injected into the air stream as a visual aid. Slides are suspended at 5-foot intervals along a rope extending from the ground to a position ten feet above the tree top.

solution is drawn out of the liquid orifice by suction from the air stream passing over it. When pressure is applied to liquid inside the tank, the drop size and liquid output increase rapidly. Drop size increases with increase in liquid pressure. This is due to increase in liquid output and only indirectly to the liquid pressure. For general use, it is best to have the liquid orifice slightly larger than the air orifice. Good combinations are: air orifice 1/16″ with liquid orifice 3/32″; air orifice 3/64″ with liquid 5/64″; or air orifice 3/32″, liquid orifice 1/8″. In general, the distance to which hand atomizers can discharge the spray corresponds roughly with that for aerosol bombs. It varies with the drop size and the size of the air orifice.

A very significant point is that cheap hand atomizers can be constructed that will deliver any type spray mixture in any of the effective drop sizes possible with the liquefied gas bombs. Moreover, they have the advantage of being readily available and may be refilled repeatedly by the user.

COMPARISON OF SPRAY VERSUS DUST DEPOSIT IN TREES. As in the case of sprays, the dust deposit becomes progressively less as distance from the duster increases, due to the decrease in air velocity needed to impinge the small particles. This fact is illustrated in Table 15 which shows a comparable relationship between dust and spray deposit at given distances vertically from a mist blower. Equal quantities of insecticides were applied (two gallons of 12 per cent DDT emulsion or 20 pounds of 10 per cent DDT dust) in each of five tests made during little or no wind movements. The average spray drop diameter was about 45 microns as compared with less than 10 microns for the dry dust. Up to 20 to 25 feet from the blower with the air velocity 40 to 125 m.p.h., the dust deposit compared favorably with spray deposit, but thereafter the dust deposit decreased more rapidly than spray deposit, so that spray deposit was a little over five times as great as dust deposit in the upper 20 feet of the tree crown. The dust cloud was projected through the tree crown to a distance of about 50 feet above the tree, and completely enveloped even the top slides which showed no deposit (Figures 5, 6, 7, and 8).

In foliar applications to the above tree, 72 per cent of the initial dust deposit was removed by wind alone in three days. The rate of loss by wind has been found to be less on lower growing trees, shrubs, and crops than on tall trees which are exposed to higher

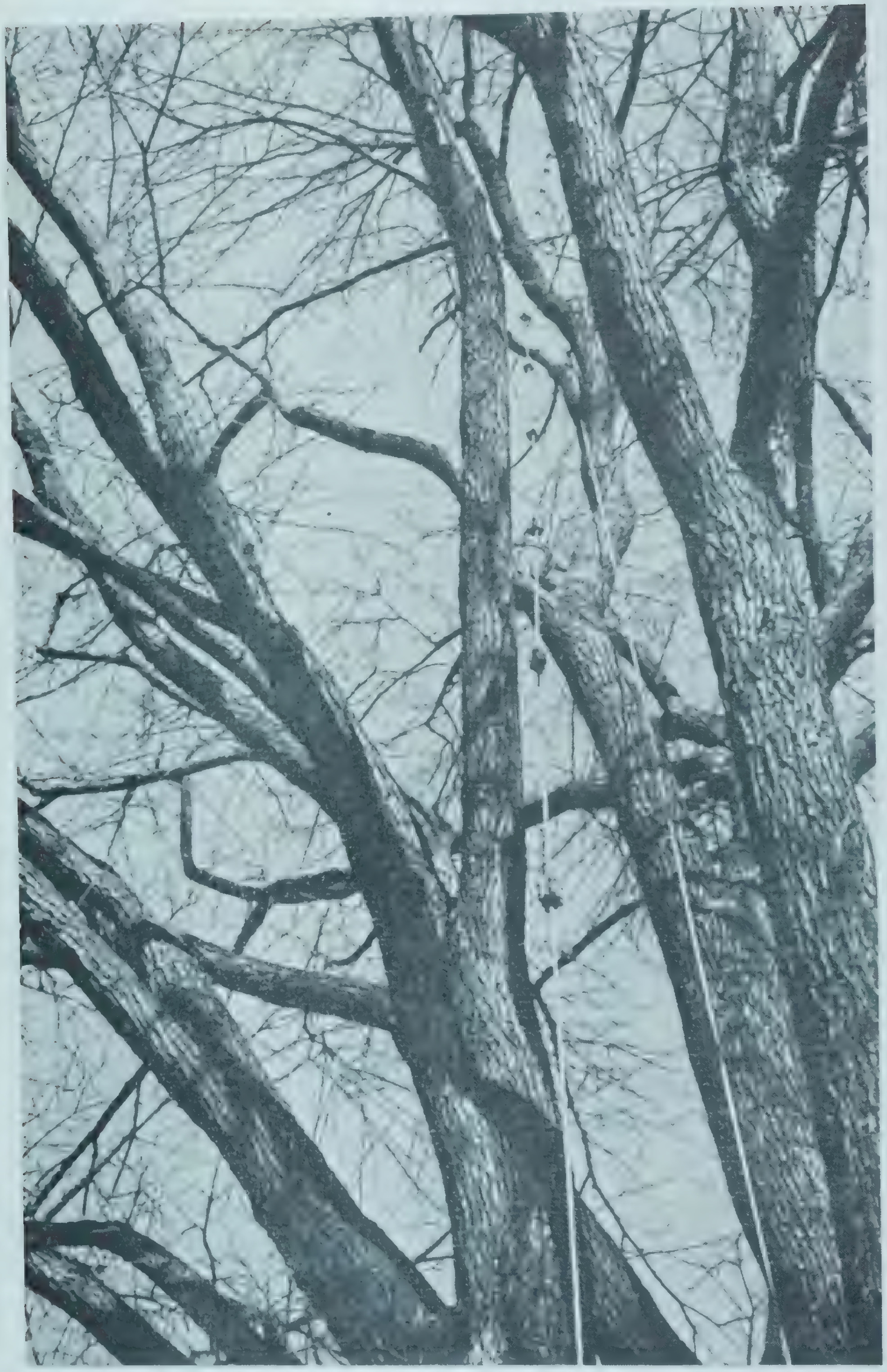


Figure 7. View of slide holders at 5-foot intervals, along a rope extending from the ground to a pulley above the tree top. The rope with slide holders is pulled up or down from the ground. This eliminates climbing and permits operation of the sampling system from the ground, so that a large number of tests can be conducted in a short period.

winds and less dew or wetting fogs. The rate of loss of dust deposits by rain is also much greater than for spray deposits.

The initial dust deposit was increased 14 per cent by wetting the surface of the slides with glycerine. See Table 15 on page 54.

Spray-Dust Application

FOR certain kinds of treatment, the simultaneous application and coating (or blending) of dust and spray may be desired, as when both dust and spray are needed or when the pesticide powder is not compatible with the liquid medium. This system increases deposit and adherence of dusts but, in most cases is not as effective as spray alone. This operation is accomplished by driving a stream of dust, preferably at high velocity (150 to 300 m.p.h.), against a liquid as the latter leaves a nozzle, and before the state of fine atomization is reached. Effective coating of dust with spray requires that the dust and spray liquid be driven against each other with considerable force while confined momentarily in a restricted space, as in a narrow outlet. The dust may be conveyed through short, small diameter (as ½ to 1 inch) hoses or pipes. The liquid nozzles are at the outlets of these pipes.

If it is desired that the spray-coated dust be carried or driven to great distances, the spray nozzles and dust outlets are placed in the mouth of a large outlet through which air is discharged from a medium or low velocity, high volume blower. The large volume of air is merely to carry and spread the insecticide and is not for improving atomization and coating. The large blower and the small one are driven by the same engine.

When the coating of dust with spray was first attempted in 1928, it was thought that the dust might be well coated by applying ¼ to ½ pint of liquid adhesive (as linseed oil or casein) per pound of dust. However, it developed that injecting such small quantities of liquid into the air-dust stream gave very poor coating of the dust until the air stream was practically saturated with spray. Therefore, it was advisable to apply one gallon of liquid per 1 to 4 pounds of dust depending on the efficiency of the mixing apparatus and on the quantity of oil or nonvolatile ingredients in the liquid phase. The importance of the size of the dust outlet as related to wetting efficiency is indicated by the estimates that 10, 15, 20, 33, and 50 per cent of the dust was well coated respectively when the two gallons of 20 per cent oil emulsion and one pound of dust

TECHNOLOGICAL RESEARCH
4938
LIBRARY

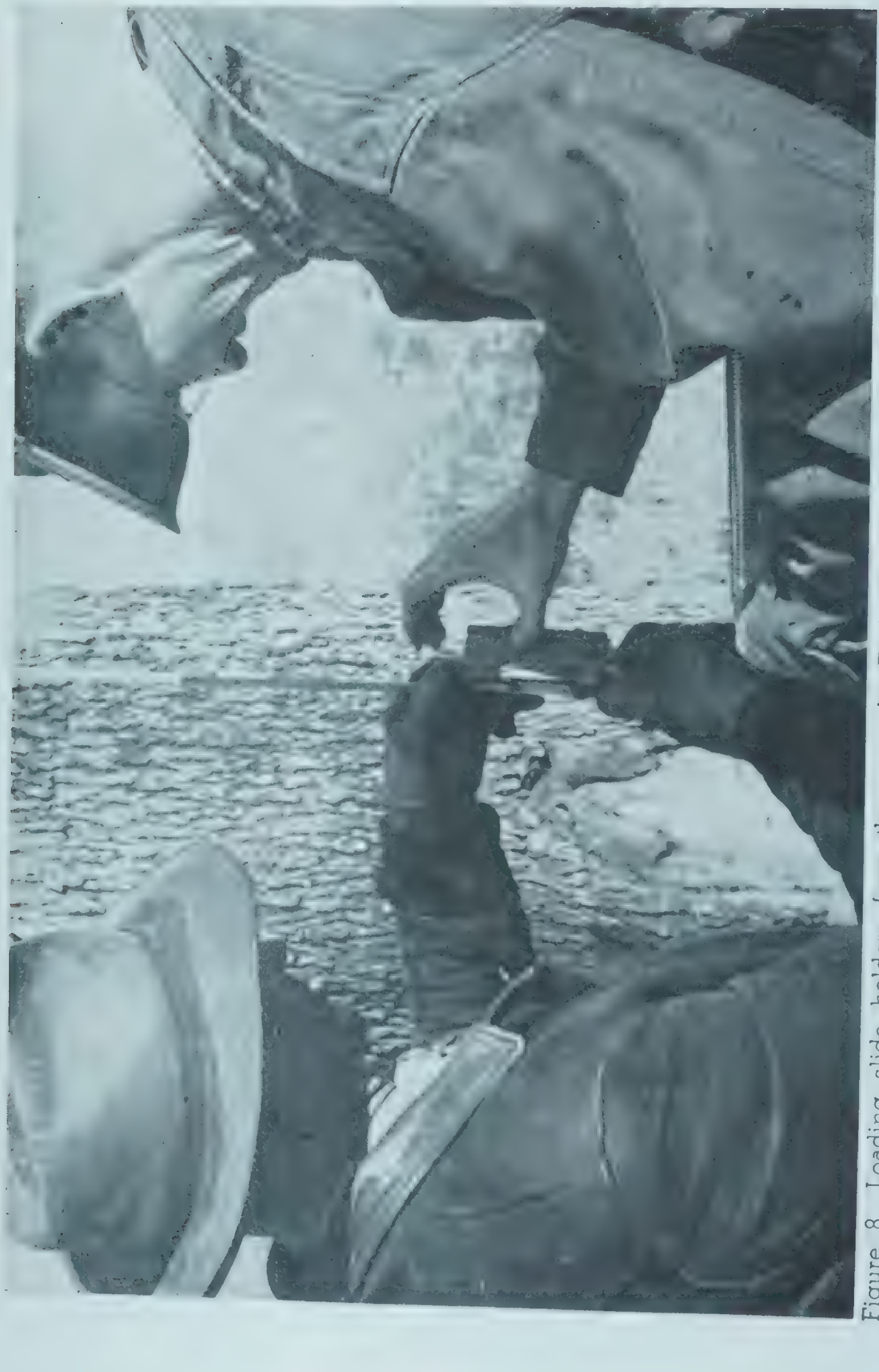


Figure 8. Loading slide holders from the ground. Each block holds four slides, with one facing each of four different directions.

were discharged per minute through outlets of respectively 24, 12, 8, 4, and 2 inches, in diameter.

The above system has been tried on aircraft as well as on mist blowers.

A typical liquid formula for coating each one to four pounds of dust consists of one to two pints of oil (as 50 seconds Saybolt viscosity white paraffin oil), containing one to two ounces of emulsifier as Triton X-100,* and water to make a gallon. Relatively nonvolatile liquids that may be used in place of oils are glycerin, glycol, and Carbowax. Insecticides may or may not be included in the liquid phase.

Plain water spray was first used in an effort to wet the dust. From 1 to 2 gallons of water was needed per pound of dust. The use of oils, emulsions, and relatively nonvolatile liquids improved the coating, reduced drying and evaporation and made it possible to use less liquid per given weight of dust.

The improvement of application apparatus was also very beneficial. Even with the most efficient formulas and apparatus, however, it is difficult to obtain a good coating of more than 50 per cent of the dust. Actually, for 100 per cent coating, each particle of dust should be coated with a quantity of oil equal to 20 to 35 per cent of its weight, depending on the size and surface area of the dust particles.

Formulas For Spray-Dust (Wet-Dust) Application

A. *Liquid phase:*

The non-volatile, non-drying mineral oil contained in some of the formulas is primarily to prevent too rapid volatilization of other ingredients.

Using water as the principal carrier instead of oil reduces the chances of foliage injury. Therefore,formulas 1 and 2 are less safe than formulas 3 to 8, and must be finely atomized and applied in low volume. Many plants may not tolerate more than 2 gallons of actual oil per acre in the summer application.

B. *Dust phase:*

Release 1 to 4 pounds of dust per gallon of liquid depending on the efficiency of the mixing apparatus and on the quantity of oil or non-volatile ingredient in the liquid phase. A given rate of dust discharge must coincide with a given rate of spray liquid discharge.

---

*Product of Rohm & Haas Co., Philadelphia.

Table 15. Relative DDT deposit on 1 x 3 inch glass slides suspended in a 70-foot elm at given heights from the ground with mist blower or duster delivering 8,000 c.f.m. of air at 135 m.p.h. through a 12-inch diameter outlet.

Feet from ground	Approximate air velocity m.p.h.	Average relative deposit* of DDT applied in dust form	Average relative deposit* of DDT applied in concentrated spray form
0	135	......	......
20	40	130	150
25	35	125	175
30	30	102	184
35	20	84	136
40	15	86	125
45	13	42	110
50	12	22	76
50	10	12	56
60	8	5	34
65	7	0	28
70	5	0	17
Total		608	1091

* To find the deposit in micrograms per square inch of surface, multiply the figures in columns 3 and 4 by 4.379.

Table 16. Air velocity required to overcome gravity of drops having a specific gravity of 1.00, applicable to vertical projection.

Diameter of drops in microns	12.5	25	50	75	100	125	150	175	200	300
Velocity V^2 of air to overcome gravity (m.p.h.)	.01	0.44	.018	0.38	0.67	1.06	1.51	2.06	2.7	6.0

The minimum air velocity (V_1) required for deposition varies inversely with the drop size and the air velocity (V_2) required to overcome gravity. When these two are added the theortical otimum drop size can be found for objects of various size.

Formulas for Spray Dust Application

Spray mixtures for coating insecticidal and fungicidal dusts:

Formula No.	Ingredient	1 gal. lot	Characteristics
1.	Kerosene or Deo-Base	7 pints	Not as safe or as adhesive as 3 and 4 below.
	Light, refined 42 to 70° oil	1 pint	
2.	Kerosene or Deo-Base	2 qts	*Highly adhesive,* not as safe as 3, 4, and 5 below.
	Light, refined mineral oil	¾ pt	
	Drying oil (as linseed oil)	3¼ pts.	
3.	Light, refined mineral oil	½ pt	*Adhesive*
	drying oil (as fish oil)	2½ pts.	
	Triton X-100 or Vatsol O.T.	3 ozs.	
	Water	5 pts.	
4.	Light, refined mineral oil	¼ pt.	*Moderately adhesive*
	Drying oil (as soybean or cotton seed)	1 pt.	
	Triton X-100, Vatsol O.T. or Tween #85	1 oz.	
	Water	6¾ pts.	
5.	Horticultural Base refined oil (36 to 45° Saybolt)	1 to 2 pts.	*Not highly adhesive*
	Triton X-100	1 oz.	
	Water	6 to 7 pts.	

6. Four to 8 ounces of Wyoming bentonite and 1 to 2 ounces of skim milk powder dispersed in water to make one gallon. Replacing 6 to 8 fluid ounces of water per gallon of mixture with 6 to 8 ounces of glycerine or other hygroscopic liquid increases dust deposit and spreading.

7. Four ounces of Geon, VL 600, or polyethylene polysulfide dispersed in water to make one gallon. Very adhesive.

8. Water alone or containing 2% Santomerse or Ultrawet spreader. Not very adhesive.

Table 17. Minimum air velocity (m.p.h.) for efficient deposition with elevation for droplets and objects of various size.

Width of objects in inches	Particle size in microns diameter								
	25u	50u	75u	100u	125u	150u	175u	200u	300u
	m.p.h.	m.p.h.	m.p.h.	m.p.h.	m.p.h.	m.p.h.	m.p.h.	m.p.h.	m.p.h.
⅛	4	1.2	0.7	.8	1.0	1.4	1.6	1.8	5.5
¼	8	2.2	1.2	1.1	1.3	1.6	2.0	2.5	5.7
½	16	4.2	2.1	1.6	1.6	1.8	2.2	2.7	5.8
1	32	8.2	3.9	2.6	2.2	2.3	2.5	2.9	5.9
2	64	16.2	7.5	4.6	3.5	3.1	3.2	3.4	6.0
3	96	24.2	11.0	6.6	4.8	4.0	3.8	3.9	6.1
4	128	32.2	14.6	8.6	6.0	4.9	4.6	4.4	6.2
8	256	64.2	28.	16.	11.0	8.0	7.4	5.4	6.3

Table 18. Air velocity, air displacement, and diameter of air stream at given distances from a 12 inch diameter outlet delivering air at 125 m.p.h.

	Distance from outlet in feet								
	0	10	25	50	75	100	125	150	200
Air velocity m.p.h.	125	60	30	7	4	2.5	1.5	1	0
Air stream (cone) diameter in feet	1	5	10	15	20	25	30	35	—
Air displacement in cu. ft. for each Frustum	0	81	687	3,108	6,054	9,981	14,889	20,780	—
Accumulative air displacement cu. ft.	0	81	768	3,876	9,930	19,911	34,800	55,580	

Analysis of Mist Blower Application

TO obtain maximum efficiency of pest control while maintaining the greatest degree of safety for plants requires optimum drop size and velocity for best coverage and deposition on leaves, needles, twigs and insects at given distances vertically or horizontally from the blower. The penetration and coverage of dense foliage requires a smaller particle size and greater air velocity than for sparse foliage and dormant trees. As the size of the particles decreases, there is a corresponding need for increasing the air velocity in order to impinge the droplets. Solution to this problem is made more difficult by the fact that air velocity decreases as distance from the blower increases, which creates the need for increasing particle size with increase in distance from the blower in order to effect impingement of the drops. Insofar as is practical, formulations should be used that do not volatilize rapidly and thereby reduce the particle size in the air.

Two sets of figures were developed in an endeavor to determine the optimum drop size. One set of figures reflects theoretical calculations based on Sell's (1931) studies of the deposition of particles in a moving air stream and on Stoke's law (Miller, 1935) showing that particles fall with a velocity depending on their diameter or surface area and specific gravity. The other figures are from practical field tests.

Sell's formula for calculating the minimum air velocity for maximum deposit is as follows: $V_1 = \frac{20{,}000\ S}{D^2}$

where, V_1 = Minimum velocity for maximum deposit in m.p.h.
S = width of object in inches
D = diameter of particles in microns

The upward air velocity required to overcome rate of fall can be computed from the formula:

$$V_2 = 0.0000\ 605\ D^2$$

where,

V_2 = Velocity of air in m.p.h. to overcome gravity oil spray weighing 7.5 lbs. per gal.
D = diameter of particles in microns.

Increasing or decreasing the specific gravity of the spray solution directly increases or decreases the air velocity required to overcome the gravity of drops.

Study of Air-Spray Streams

SPECIAL investigations were made of air streams, especially those from round outlets. High air velocity reduces the spreading of air streams. Air streams spread as air velocity diminishes. Low air velocity and large air volumes facilitate the spreading of air streams. For example, when air was delivered through a 12-inch diameter outlet at 100 m.p.h. the air stream diameter at 50 feet from the machine was 20 per cent greater than when it was delivered at 125 m.p.h. However, at a distance of 100 feet, the air stream from the 125 m.p.h. velocity stream was slightly wider

Experiment No. 1

Average numerical diameter of 35 seconds S U V oil droplets at two-foot intervals along two bisecting lines of a two-foot mesh vertical test screen of 20 x 21 feet located 50 feet from the mist blower.

Wind 3 to 5 m.p.h.

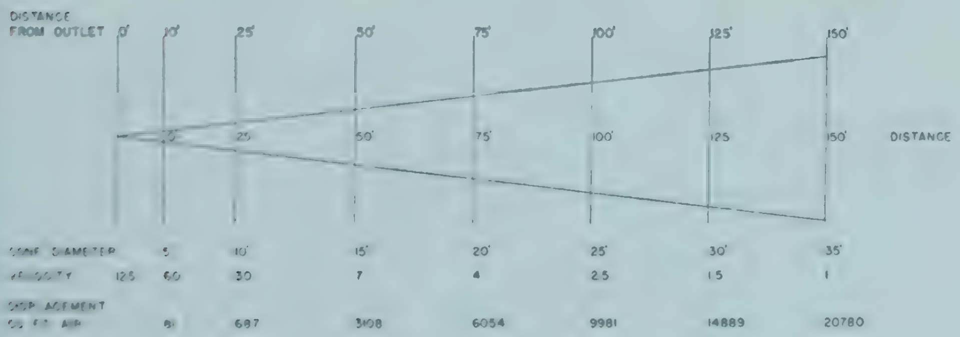
	A	B	C	D	E	F	G	H	I	J	K
						45					
1						50					
2						55					
3						56					
4						56					
5	35	40	52	55	57	60	60	62	63	63	66
6						58					
7						63					
8						66					
9						67					
10						69					

than for the 100 m.p.h. stream which had practically ceased forward movement at that distance (Figure 9). In the absence ot wind, the extent of spread of an air stream is closely related to the volume of air that it displaces. Rate of coverage is roughly proportional to air displacement whether by "manufactured" air, or by natural air movement (Figure 13, page 70).

Table 18 shows the air velocity, air displacement, and diameter of an air stream at given distances from a 12-inch diameter outlet delivering air at 125 m.p.h. (Table 18 appears on page 56)

Tabulations below from experiments 1, 2, 3, 4 and 5 give the DDT and lead arsenate deposit and drop size measurements from mist blower applications to a large, two foot mesh screen, 20 x 22 feet (440 square feet). Test sample objects such as 1 x 3 inch microscope slides, twigs, leaves, etc., were attached and held by metal friction clamps at each place on the screen where any two wires intersected. This provides 110 intersections, or one per four square feet (Figure 10).

This test screen was used in experiments to obtain the following information: (1) the diameter or shape, and distribution pattern of spray streams from outlets of given size and shape when sprays of given average drop size are applied with given air velocities and volumes. (2) the percentage of spray applied that is recovered on objects of given size and shape for given drop size patterns and air velocities (Table 19).


DISTANCE FROM OUTLET
0'
10'
25'
50'
75'
100'
125'
150'
10'
25
50'
75'
100'
125
150'
DISTANCE
CONE DIAMETER
5
10'
15'
20'
25'
30'
35'
VELOCITY
125
60
30
7
4
2.5
1.5
1
DISPLACEMENT CU FT AIR
81
687
3108
6054
9981
14889
20780

DIAGRAMATIC ANALYSIS OF AIR STREAM FROM 12—INCH OUTLET AT 125 M.P.H.

Figure 9.

Experiment No. 2

Lead arsenate deposit in milligrams per square inch on 1 x 3 inch slides on a 20 x 22 foot screen at 25 feet from a 12 inch diameter outlet delivering air at 125 m.p.h. The mixture was a water suspension containing 2 pounds of lead arsenate and 7 ounces of oil per gallon, and was delivered through No. 2 Whirljet nozzles at 50 p.s.i.

Row No.	A	B	C	D	E	F	G	H	I	J	K
0	.12	.22	.40	.50	.87	.87	.50	.33	.12	.0	.0
1	.25	.67	1.2	1.3	.87	1.3	1.2	.67	.22	.13	.10
2	.22	.67	1.2	1.3	1.3	1.2	1.2	.50	.25	.15	.10
3	.21	.63	.67	1.3	1.3	1.3	.67	.33	.22	.15	.10
4	.18	.50	.60	1.3	1.5	1.2	1.0	.40	.25	.17	.12
5	.16	.16	.63	1.3	1.3	1.2	1.0	.42	.33	.17	.12
6	.17	.30	.22	.67	.83	.67	.67	.60	.33	.17	.15
7	.17	.25	.20	.50	.70	.50	.40	.30	.25	.12	.10
8	.15	.17	.17	.30	.40	.30	.30	.25	.20	.15	.12
9	.12	.15	.15	.25	.22	.33	.22	.17	.15	.14	.12
10	.10	.10	.12	.17	.15	.17	.15	.15	.12	.10	.0
	A	B	C	D	E	F	G	H	I	J	K

Experiment No. 3

DDT Deposit in micrograms per square inch on 1 x 3 inch slides on 20 x 22 foot screen 25 feet from 12 inch diameter outlet delivering air at 125 m.p.h. Mixture was a 12 percent DDT-oil solution delivered through No. 2 Whirljet nozzles at 50 p.s.i.

	LINE										
Row No.	A	B	C	D	E	F	G	H	I	J	K
0	87	96	162	114	143	87	37	5	2	2	1
1	88	86	158	248	149	101	40	6	2	3	2
2	84	58	269	311	733	591	404	76	4	2	2
3	85	202	411	1263	2062	2448	2062	520	30	2	2
4	82	201	504	1353	2191	1804	2448	1031	115	8	4
5	93	238	522	1664	2218	2088	1305	1305	57	3	4
6	104	217	483	607	1153	1001	543	143	26	5	3
7	159	165	314	415	411	232	70	18	6	3	2
8	100	88	119	108	55	26	20	11	4	2	1
9	60	40	60	40	20	10	10	6	2	1	0
10	10	10	15	10	4	4	2	2	0	0	0
	A	B	C	D	E	F	G	H	I	J	K

Experiment No. 4.

Lead arsenate deposit in milligrams per square inch on 1 x 3 inch slides on 20 x 22 foot screen at 25 feet from a 12-inch diameter outlet delivering air at 125 m.p.h. Mixture was a water suspension of 2 pounds of lead arsenate and 7 ounces of oil per gallon.

Wind, 3 to 5 m.p.h.

Row No.											
1	.17	.23	.25	.22	.17	.15	.15	.15	.13	.13	.12
2	.14	.22	.23	.25	.17	.17	.16	.15	.13	.14	.10
3	.22	.44	.67	.35	.33	.17	.18	.17	.17	.16	.15
4	.58	1.3	2.4	2.0	1.3	.25	.30	.23	.17	.17	.17
5	.30	2.3	5.1	5.9	4.0	.67	.30	.23	.15	.15	.16
6	.26	2.3	3.8	4.0	4.0	.67	.20	.17	.17	.15	.13
7	.33	2.3	2.6	4.0	4.0	.67	.20	.17	.17	.15	.14
8	.18	1.2	2.0	2.3	2.2	.57	.40	.17	.17	.15	.15
9	.15	.58	.67	.67	.28	.15	.15	.15	.15	.15	.15
10	.17	.27	.33	.17	.15	.12	.15	.15	.15	.17	.17
	A	B	C	D	E	F	G	H	I	J	K

Experiment No. 5

Lead arsenate deposit in milligrams per square inch on 1 x 3-inch slides on a 20 x 22 foot screen at 15 feet from a 12-inch diameter outlet delivering air at 125 m.p.h. The mixture was a water suspension containing 2 pounds of lead arsenate and 7 ounces of oil per gallon, and was delivered through No. 2 Whirljet nozzles at 50 p.s.i.

Row No.											
1	.0	.0	.2	.3	.3	.33	.3	.2	.10	.0	.0
2	.0	.0	1.2	.5	1.0	1.0	1.0	.7	.3	.15	.0
3	.0	.0	.7	1.4	1.7	1.6	1.3	1.0	.5	.12	.0
4	.10	.3	.8	2.0	2.1	2.0	1.4	1.3	.8	.20	.0
5	.0	.22	.75	1.7	1.8	2.0	1.5	1.5	1.0	.33	.0
6	.10	.2	.8	2.0	2.2	2.5	1.6	1.4	.8	.3	.0
7	.10	.5	1.2	1.4	1.8	1.8	1.4	1.2	.7	.25	.0
8	.0	.3	.7	1.0	1.4	1.2	1.6	1.0	.6	.10	.0
9	.0	.10	.3	.75	.66	.75	.7	.5	.10	.0	.0
10	.0	.10	.15	.2	.3	.10	.10	.10	.10	.0	.0
	A	B	C	D	E	F	G	H	I	J	K

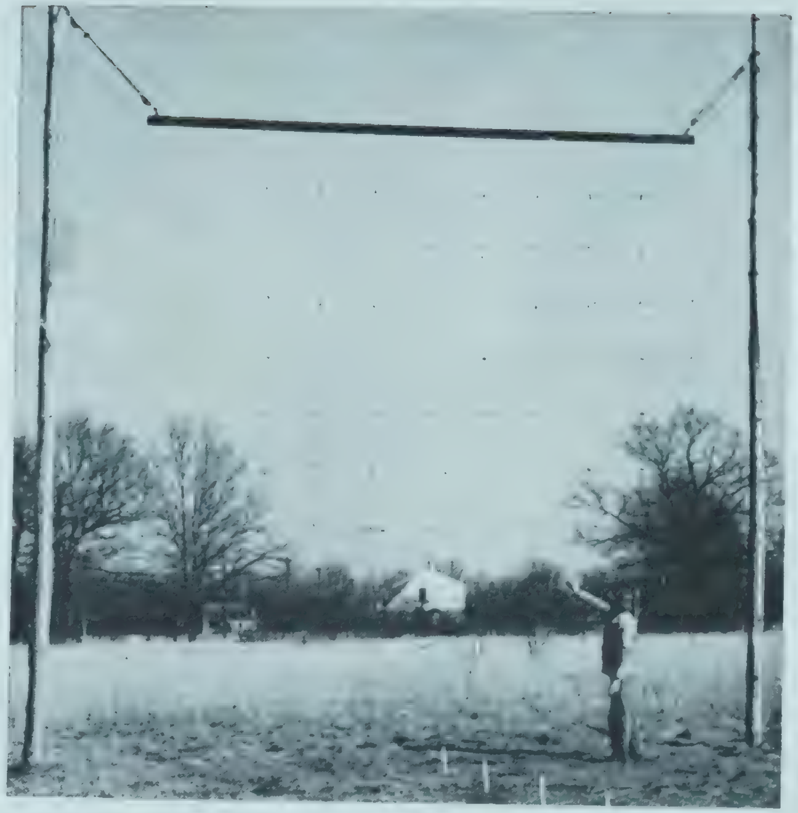


Figure 10. A vertical two-foot mesh, test sampling screen 20 x 20 feet. Deposit sample slides, twigs, leaves, or other objects are attached to clamps on the screen at each 2-foot intersection of wire

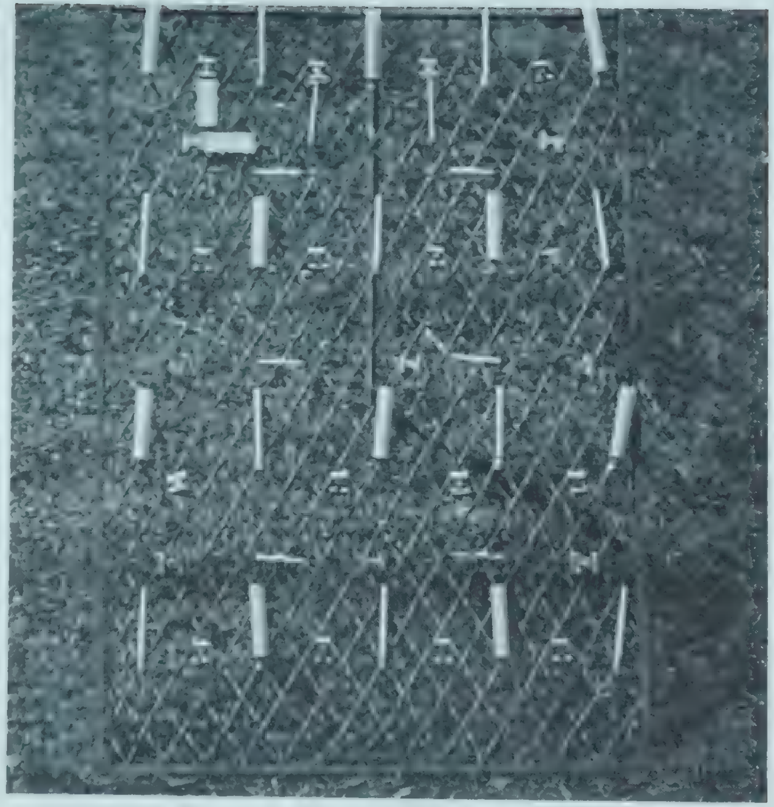


Figure 11. A small frame, about $4\frac{1}{2}$ x 6 feet for suspending objects such as glass cylinders, slides, discs, for catching deposit samples

To calculate the total deposit, the deposit per square inch or per square foot on each of the 110 sample objects is multiplied by four square feet (576 square inches, the area of each 2 x 2 foot square). Then add the quantity of deposit for each of the separate samples (2′ x 2′ compartments) to find the total deposit for the entire screen or cross section of the air stream. Then, to learn the *percentage* of spray recovered, divide the total deposit recovered by the total quantity of insecticide applied. To learn the quantity applied, calibrate the machine for gallons delivered per minute, and per second. For example, if the machine delivers 60 gallons per hour, then one gallon would be applied per minute or 63 milliliters (2.2 ounces) per second. If the spray machine runs for six seconds, 0.1 gallon or 378 milliliters would be applied. If the mixture contains 1, 2, 3, etc., pounds of insecticide per gallon, then 45, 90, 155, etc., grams of insecticide would be applied. Quantity applied depends on rate of delivery, spraying time, and pounds of insecticide per gallon. A deposit of one pound of insecticide per acre of surface is at the rate of 0.0723 milligram or 72.3 micromilligrams per square inch or 11.21 micromilligrams per square centimeter. When making these tests the spray was usually released for 5 to 15 seconds and a quick-acting shut-off valve used to turn the spray on and off.

The number of droplets on a given area depends on the total quantity of deposit per given area and the original diameter of the droplets. In studying the distribution of drops of given size in air streams delivered horizontally, it was observed that, as air velocity diminishes, the heavier droplets move towards the bottom of the air stream. If there is a cross breeze, the droplets move with the breeze at a rate depending on the velocity of the manufactured air stream, the speed of the wind, and the square area of the droplets.

The diagram in experiment No. 1 shows the drop size distribution on the above screen when an air-spray stream containing droplets averaging 42 microns in diameter was delivered at 125 m.p.h. The screen was 50 feet from the blower and the manufactured air velocity at the screen was 8-10 m.p.h. There was a mild, 3 to 5 m.p.h. cross breeze, moving from right to left. The figures on the diagram show the average diameter of droplets from right to left and from top to bottom of the screen.

Table 19 showing the percentage of spray recovered on glass slides one inch wide when sprays of given degrees of atomization were delivered to the screen at given velocities.

Average drop diameter, microns	Diameter of air outlet in inches	Air velocity at screen in m.p.h.	Percent of spray recovered on slides
2*	2	3	0**
15	12	5	7
15	12	40	28
26	12	20	34
26	12	40	45
42	12	10	40
42	12	20	62
42	12	40	70
66	12	40	86
90	12	35	90
125	12	35	92
40	5	10	46
25	5	10	22
10	5	8	6

* Thermal aerosol.
** Less than 1 percent.

Table 20. Showing diameter of drops resulting from the evaporation of the volatile portion of solution or emulsions containing 12.5 per cent by volume of non-volatile liquid or powder.

Original diameter of drop microns	Diameter of drop after evaporation of volatile ingredients		
	50 per cent	75 per cent	100 per cent
200	167.	139.	100.
150	125.	104.	75.
100	84.	70.	50.
75	63.	52.	37.5
60	50.	42.	30.
50	42.	35.	25.
40	33.5	28.	20.
30	26.	21.	15.
20	17.	14.	10.
10	8.	7.	5.

Special Screen Deposit Tests

A NUMBER of deposit recovery tests were made with objects of various size and shape attached to large and small screens. The objects were oval, disc, cylindrical, square, and oblong in shape. They varied in size from 1/16 inch to three inches in diameter. The great number of tests needed for accurate data did not permit a completion of enough replicates for the complete series of all sizes and shapes of objects. However, the tests showed a close correlation between the width or diameter (in case of cylinders) of objects and the drop size and velocity required to give efficient deposition. Deposits on both cylinders and flat objects were proportional to their width or diameter. (Figure 11.)

Deposit tests on a 16-mesh copper wire screen* were particularly interesting. The strands in the screen were 275 microns in diameter. They represented 17.32 per cent of the area of each mesh or screen, leaving an open space of 82.68 per cent (100-17.32). Five replicated tests were made. The application was made with a Potts-Spencer mist blower dispersing a 15 per cent lead arsenate suspension containing 5 per cent emulsifiable oil, at a distance of 25 feet from the screen. At the screen the air was moving at 8 m.p.h. with the help of a three mile breeze. The numerical average drop diameter was 36 microns. The area of the screen was 158 square inches. In the tests four 1 x 3 inch slides were attached directly in front of the screen and four similar slides were suspended directly back of the screen to sample what went through.

The analysis showed a lead arsenate deposit of 1.145 milligrams per square inch on the slides in front of the screen as compared with 3.17 milligrams per square inch for the wire. The slide in back of the screen caught a deposit of 0.685 milligram of lead arsenate per square inch. These data show that for fine droplets the fine wires catch a large percentage of the spray, whereas it tends to flow around the 1 x 3 inch sides. It was not determined whether the fine copper wires attracted the fine droplets. It was noticed, however, that at three miles or less there was some tendency for the air stream to flow around the screen as though it were exhibiting some resistance to air flow that has been shown by foliated trees and branches of closely matted foliage.

---

* One-sixteenth of an inch equals 1587 microns.

Effect of Evaporation of Droplets on Deposit

THERE has been a great deal of speculation as to the extent to which droplets of given size evaporate in the air stream or while floating in the air. Moreover, there have been many inquiries as to what diameter droplets may assume after different degrees of evaporation have taken place. The extent of evaporation depends on a number of factors; the more important of which are (1) the proportion of relatively non-volatile liquids and solids in the mixture, (2) the temperature, humidity and wind velocity, (3) the droplet size (since small volatile droplets evaporate faster than large ones), and (4) the length of time that the droplets are airborne. In some cases, too much emphasis has been placed on the evaporation factor. In other cases, too little attention has been devoted to it and not enough has been done about it.

Table 20 shows the diameter of droplets after losses of 50, 75, and 100 per cent of the volatile portion of solutions or emulsions containing 12.5 per cent by volume of non-volatile liquid or powder. It is significant that as liquid evaporates from a drop its diameter changes less rapidly than its volume. For example, for a drop to lose one-half of its diameter it must lose ⅞ths of its volume.

Drops that are 100 microns or more in diameter can lose up to 80 per cent of their weight or volume without materially affecting the residual deposit of their non-volatile ingredients. On the other hand, if the initial diameter of the droplets is 60 microns or less

Table 21 showing the effect of evaporation on drop diameter.

Per cent evaporated by volume	per cent not evaporated by volume	Diameter of drop, microns
0.	100.	100.
50.	50.	79.6
75.	25.	63.
87.5	12.5	50.
93.75	6.25	39.7
96.87	3.13	31.5
98.44	1.56	25.

the loss of 75 per cent or more of the volume of the drops can materially affect insecticidal deposit unless there is sufficient air velocity at the target to effect impingement.

The extent to which a given drop's dimensions can shrink by evaporation is first limited by the proportion of relatively non-volatile liquids and solids in the mixture. For example, in liquid mixtures containing no volatile ingredients (as ordinary motor oil)

Table 22. DDT residue on samples of alfalfa treated with a 25 h.p. mist blower delivering 7500 c.f.m. of air through a 12 inch diameter outlet.

Test No.	Formula	Distance from machine in feet	DDT in parts per million
1	DDT 3 pounds, Xylene 3.6 quarts, kerosene to make 3 gallons.	50	118
		150	67
		250	37
		350	15
2	DDT 5 pounds, Xylene 6¼ quarts, No. 10 motor oil 4 quarts, Kerosene to make 5 gallons.	50	171
		150	46
		250	23
		350	9
3	DDT 5 pounds, Xylene 6¼ quarts, Triton X-100 ¾ pint, water to make 5 gallons.	50	303
		------	------
		250	12
		350	9
		450	8
		550	3
4	DDT 5 pounds, Xylene 6¼ quarts, Triton X-100 ¾ pint, water to make 5 gallons.	50	476
		150	85
		250	43
		350	23
		450	20
		550	15
		650	12
5	DDT dust (2 per cent DDT in pyrophyllite carrier)	50	17.1
		150	9.4
		250	7.3
		350	1.5

there is no evaporation and therefore no change in drop size. Table 21 shows that when drops lose 50, 75, 87.5, 93.75, 96.87, and 98.44 per cent respectively of their volume, their diameter is reduced by only 20, 37, 50, 60, 68.5, and 75 per cent, respectively.

The kind and quantity of solids per gallon greatly limits the reduction of drop size through evaporation. For example, when a water suspension contained ¼, ½, 1, 2, or 3 pounds of lead arsenate per gallon, the volume remaining after evaporating all of the water was 5, 10, 20, 40, and 60 per cent of the original, respectively. These five concentrations are 8.3, 16.6, 33, 67, and 100 times the concentration of a conventional dilute spray containing three pounds of lead arsenate per 100 gallons of water. In the case of some wettable powders, the residue volume remaining after evaporation is greater per pound of solids (as in the case of derris) than for lead arsenate; while it is less for mixtures containing some other powders like wettable sulfur and cryolite. The mixtures range in specific gravity from 0.88 for light oils without dissolved solids, to a maximum of 1:5 for the heaviest mixtures containing solids.

From the above figures, it is conceivable that serious evaporation might take place when water suspensions of less than 10x concentration are applied in finely atomized form in hot, dry weather unless some deliquescent or non-volatile liquid is added to minimize evaporation. Such a liquid should be reasonably inexpensive and compatible. The cheap mineral oils having a Saybolt U. V. of 45 to 75 seconds are well suited for adding to mixtures in which they are compatible. Mixtures with which oils are not compatible include those containing wettable DDT, lime-sulfur, Dithane, Puratized, and Phygon. For these mixtures and many others, certain hygroscopic liquids like glycerin, diethylene glycol, and water soluble "Carbowax" compounds are useful. Using as little of these materials as four fluid ounces per gallon of mixture, or 2 to 4 ounces per pound of solids contained in the mixture, is very helpful in cases where evaporation loss is a serious factor.

While spray drops containing water are being carried in the blower's air stream, the evaporation rate from blower to foliage is usually not sufficient to greatly affect deposit. However, when drifting the spray for long distances as when treating for mosquitoes or in orchard machines designed to throw an enveloping cloud of water-borne insecticide over the tree tops instead of directly to the foliage, there may be an excessive loss of fine particles that desiccate and float off with the wind. Therefore, time and the humidity of the air stream are two factors concerned in spray evaporation before it reaches the foliage.

Some studies were made of the relative humidity in air-spray streams delivered at 125 m.p.h. through a 12-inch diameter outlet when the temperature averaged 86°F. and the relative humidity 40 per cent. From 3 to 4 seconds were required for the spray droplets to go 50 feet. The observations indicated that when 0.5 to 2 gallons of water were finely atomized into the air stream it raised the humidity considerably. The humidity of the air-spray stream diminishes as the rate of sprayer travel increases and as the rate of water delivery decreases.

A large number of tests were made using mists with an average drop diameter of 45 to 50 microns to determine whether there was any measurable loss of deposit through evaporation when DDT solutions, emulsions, and suspensions in various solvents and carriers of different degrees of volatility were applied to tall trees. These tests showed that there was no measurable difference in DDT deposits from solutions and emulsions containing 5, 6, and 12 per cent DDT (equivalent to 0.4, 0.5 and 1.0 pound of DDT per gallon) regardless of the solvent and carrier used. This was true even for temperatures of 80 to 95°F. Water suspensions of 6 to 12 per cent wettable powder DDT or lead arsenate gave essentially the same deposit as for the solutions and emulsions of the same insecticide content. There was some indication that at elevations above 50 feet from the ground there was some loss of deposit from water-borne suspensions containing 2 per cent or less of the powder. However, there was no noticeable loss of deposit when four ounces or more of non-volatile liquid were added per gallon of mixture.

In treating row crops and nurseries with the above machine there was no noticeable loss by excessive evaporation of water-borne sprays within 40 to 50 feet of the machine. Beyond a distance of 50 feet there was some loss when the mixture did not contain an additive to minimize the effect of evaporation. All tests of the concentration were at rates greater than 6X.

Lateral Deposit from Mist Blowers

TABLE 22 shows the DDT deposit in parts per million on desiccated alfalfa samples * from nine square feet at given distances

---

* Tests conducted at Lynnhaven, Va., and Beltsville, Md., in 1946.

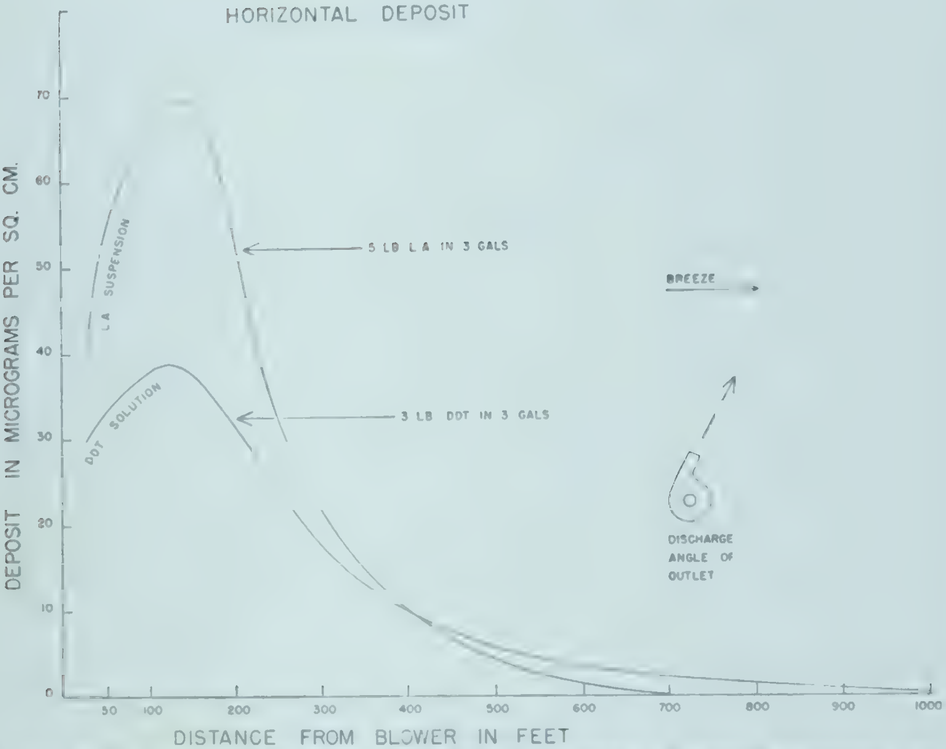


Figure 12. Showing DDT and lead arsenate deposit at given distance horizontally from a mist blower delivering 126 mph of air through a 12-inch diameter outlet

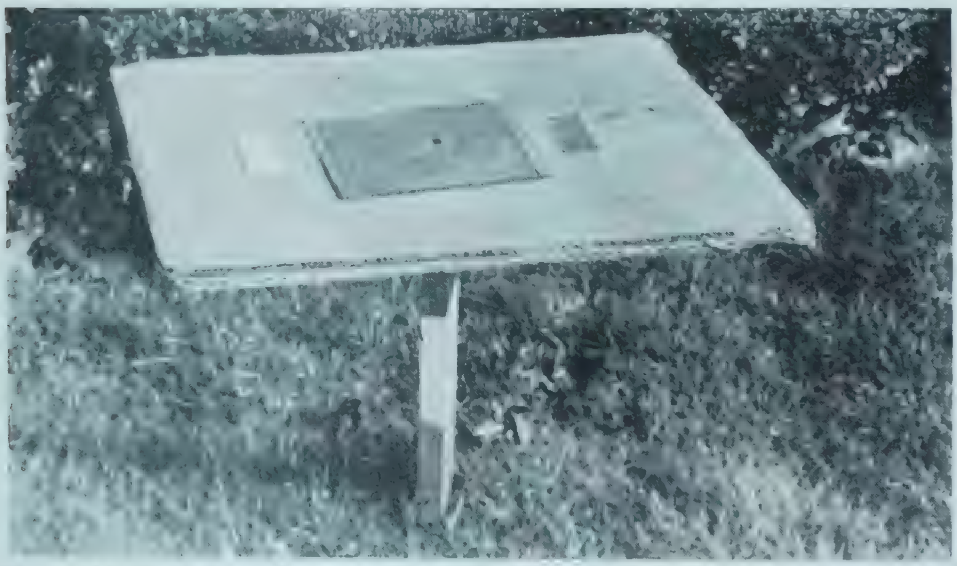


Figure 13. A method of obtaining deposit samples at given distances laterally from mist blowers. Glass or aluminum deposit plates and slides are suspended on tops of stakes at intervals along straight lines from the machine. Slides may also be suspended in a vertical position in a slide holder or rack attached to a 3′ to 6′ rod.

from a mist blower delivering 7500 c.f.m. of air through a 12-inch diameter outlet at 125 m.p.h. The spray was delivered at the rate of one gallon per 66 feet of linear travel with all applications from one side of the plot or field. The machine traveled an average of 0.75 m.p.h. by moving about 1.5 m.p.h. between short stops of 8 to 15 seconds about every 30 feet. While moving, an attempt was made to cover the area close to the machine and to avoid skips. At each stop the spray was directed into the air at an angle of 30 to 60 degrees from the horizontal so as to drive and drift the spray to considerable distance from the machine.

The deposit data and observations showed that there was a heavy deposit within 75 feet of the machine and that it was difficult to obtain even deposition with the above procedure. If the treatment can be made from two opposite sides of a field, plot, or swath, the deposit is much more uniform. Also, when treatment is made from one side of the field, the distribution can be evened up considerably by first making one application to the area close to the blower with the latter traveling 1 to 2 m.p.h. while delivering a relatively low spray output; and then making another application with four times as much spray from still positions at 20 to 30 foot intervals as described above in order to drive and drift more spray to greater distance. This procedure deposits less spray close to the blower and more spray at considerable distance from it. When this system was used, the average DDT deposit at distances of 50, 100, 150, 250, 350, 450, and 550 feet from the machine was 108, 94, 72, 64, 42, 28, and 23 p.p.m. The application was with formula 1 of Table 22 with a four mile per hour breeze. The samples were taken along three parallel lines 100 feet apart.

The deposition rate on 6 x 6 inch slides laid on the ground or on stakes (Figure 13) at 50 feet intervals for a distance 1000 feet from the above 25 h.p. mist sprayer is shown in the graph (Pg. 72). From a standing position, three applications were made with a lead arsenate suspension containing five pounds of lead arsenate and one pint of motor oil plus water to make three gallons; and three applications of 12 per cent DDT—Xylene—No. 2 fuel oil solution. Application was at the rate of one g.p.m. during a 3 to 6 m.p.h breeze. The average drop diameter for the DDT solution was about 50 microns. The spray was discharged up into the air at an angle of 60 to 65 degrees from horizontal (25-30 degrees from vertical) to obtain maximum distance from the machine. The data (Figure 12) show

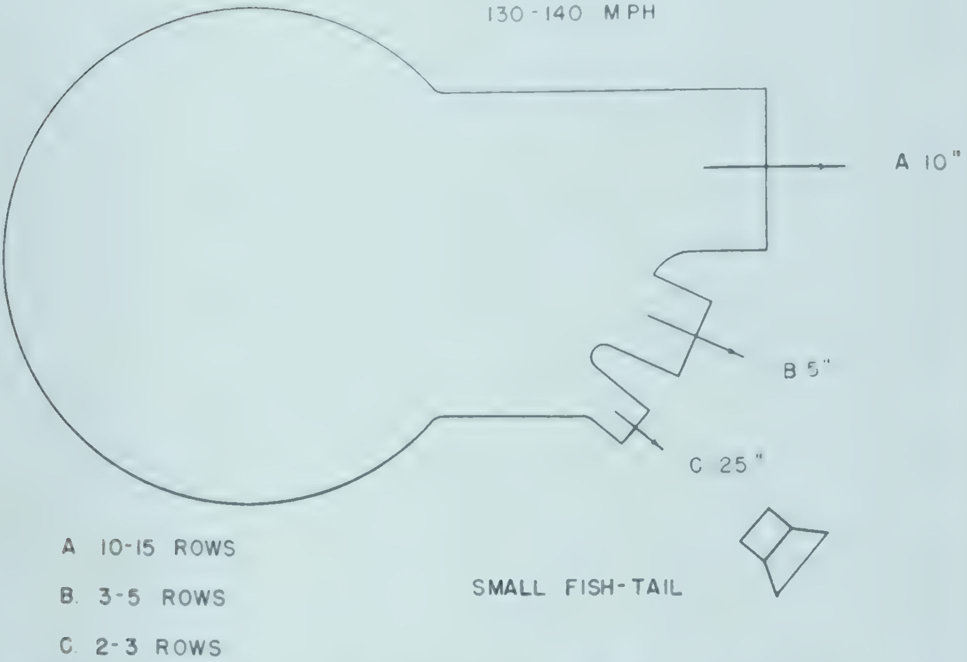

130-140 MPH
A 10"
B 5"
C 25"
A 10-15 ROWS
B. 3-5 ROWS
SMALL FISH-TAIL
C. 2-3 ROWS

Figure 14. A 3-hole outlet for use on 12 to 40 hp. mist blower for treating nurseries and crops, and for broadcasting. The two smallest outlets cover area close to the machine. The large outlet delivers spray beyond the areas covered by the smaller outlets.

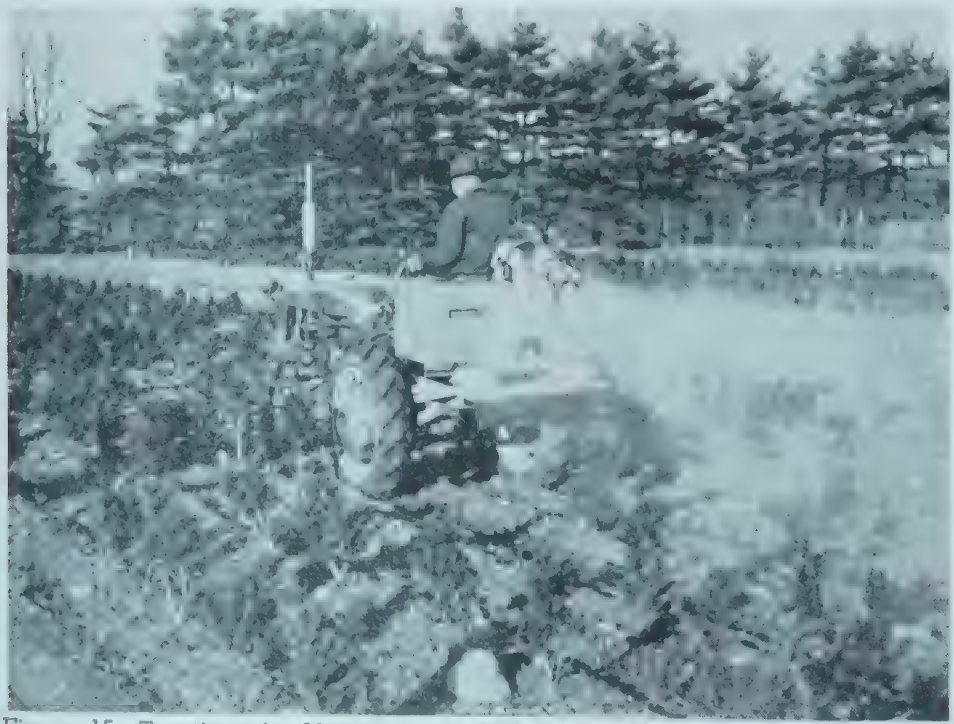


Figure 15. Treating six, 30-inch rows of nursery stock with 6 hp mist blower mounted four feet above the ground on a Farmall cub tractor.

that: deposit dropped off rapidly beyond 250 feet from the machine; there was no deposit in the first 15 feet from the outlet, and the DDT-oil solution spray carried a little further than the lead arsenate suspension. The maximum deposit was 130 feet from the machine. At the same air velocity and angle of delivery the maximum deposit for 12 and 6 h.p. mist blowers was 90 and 60 feet, respectively. For a 50 h.p. machine delivering 24000 c.f.m. of air at 95 m.p.h. it was 155 feet, and for a 1¾ h.p. wheelbarrow mist blower delivering air at 220 m.p.h. through a 1¼" diameter outlet the maximum deposit was at 35 feet from the outlet.

Swaths or strips of 75 feet or less of row crops, pastures, and nursery stock can be covered fairly well with the above machine traveling 1 to 1.5 m.p.h. This requires a driver and an experienced operator. The latter directs the greatest portion of the spray towards the border of the strip farthest from the blower, since the largest drops and the greatest number of drops have a tendency to deposit near the machine. For special tractor or trailer row crop mist blowers of 15 h.p. capacity or less, a special row crop attachment (Figure 15) has been devised for efficient application by one man.

To enable the 15 to 50 h.p. machines to treat the above strips or swaths efficiently with one man, a special type outlet was designed (Figure 14). The height of the outlet can be set in advance of spraying. It is so designed as to emit ⅛ of the total air volume through the small lower outlet for coverage close to the machine; 2/8 of the total air volume through the center outlet; and ⅝ of the total air volume through the top outlet. The amount of spray delivered through each outlet should be in relative proportion to the amount of air emitted through it.

Application to Fruit and Shade Trees

IN the practical application of mist blown insecticides, the optimum drop size for best coverage and penetration is usually less than is indicated by theoretical calculations. This is due partly to a tendency of the large droplets to work towards the outside of the air stream and drift downward as air velocity diminishes, and to the fact that during the foliar period there may be several layers of foliage to cover from top to bottom of the canopy as well as when going through the canopy of a tree from one side to the other. Best penetration and coverage of foliage is obtained by accomplishing a fairly low deposition efficiency on the first layer

Table 23. Deposit distribution through canopy of a 30 foot apple tree for two outlets delivering 8000 c.f.m. of air at 126 m.p.h. velocity.

Position No.	12 inch diameter outlet		Fish tail outlet, 3 x 38 inches	
	Treatment from one side	Calculated deposit for treatment from two opposite sides	Treatment from one side	Calculated deposit for treatment from two opposite sides
	per cent	per cent	per cent	per cent
1	38	23	66	34
2	26	19	18	11
3	16	16	10	10
4	12	19	4	11
5	8	23	2	34

Table 24. Deposit distribution through canopy of a 30 foot apple tree using a 6 h.p. mist blower with 5 inch diameter outlet at 1 m.p.h. travel rate.

Position No.	Treatment from one side	Calculated deposit for treatment from two separate sides
	per cent	per cent
1	45	26.5
2	27	16.5
3	14	14.
4	6	16.5
5	8	26.5

Table 25. DDT Deposit relationship on elm twigs ⅛ to ⅜ inch in diameter from trees 50 to 80 feet tall, top and lower crown, using equivalent dosages.

Method of Application	No. of trees sampled	Top crown	Lower crown	X Lower/top
		p.p.m.*	p.p.m.*	
Hydraulic Sprayer	127	139.6	470.4	3.4
Mist blower	97	239.5	589.9	2.5

* Parts by weight of DDT deposited per million parts by weight of twigs.

of foliage, but obtaining the maximum total deposition before the spray reaches the far side. Repeated tests have indicated that for best results 30 to 40 per cent should be deposited on the outside leaves.

The position of the machine in relation to its distance from the trunk or bole of the tree affects the efficiency of coverage. Best coverage results when the machine is close to the tree trunk, because the foliage becomes a barrier to the wind. Also, this position reduces the number of layers of foliage through which the spray stream must penetrate, and there is less foliage between the outlet and the top portion of the tree crown. Hence, there is a minimum of screening out of spray enroute from the mist blower to the tree top. Moreover, when the blower is close to the tree bole and directly under the tree crown, a better under-leaf coverage results than when the spray is directed through the side of the tree from further out. For example, when a 70-foot elm was sprayed with the blower three feet from the tree trunk, 60 per cent of the leaf deposit was on the lower surface and 40 per cent on the upper surface. When sprayed with the machine 50 feet from the bole, 24 per cent of the deposit was on the lower surface and 76 per cent on the upper surface. Reliable deposit data for elm trees treated by hydraulic sprayers is not available. However, when hydraulic sprayers treated an oak woodland of trees 50 to 60 feet in height, 83 per cent of the deposit was on the upper leaf surface as compared with 17 per cent on the lower surface. Apparently a large proportion of the deposit on the upper leaf surface was due to drippage and to spray falling back from higher levels.

Table 23 shows how the spray deposit diminishes in the canopy of a 30-foot, open grown apple tree as the spray stream passes from the side next to the blower to the opposite side. The average drop diameter was about 52 microns. Two gallons of lead arsenate mixture were applied per tree. The data show that the round outlet drove more spray to the opposite side of the tree and that more of it was deposited beyond the first (outer) layer of leaves than for the fish-tail outlet. The machine traveled 1.5 m.p.h., but in case of the round outlet the blower was 25 feet from the tree to give the air stream a chance to spread to a diameter of 12 to 15 feet before reaching the tree. Position one is at the first layer of leaves from the machine, position two is half way between

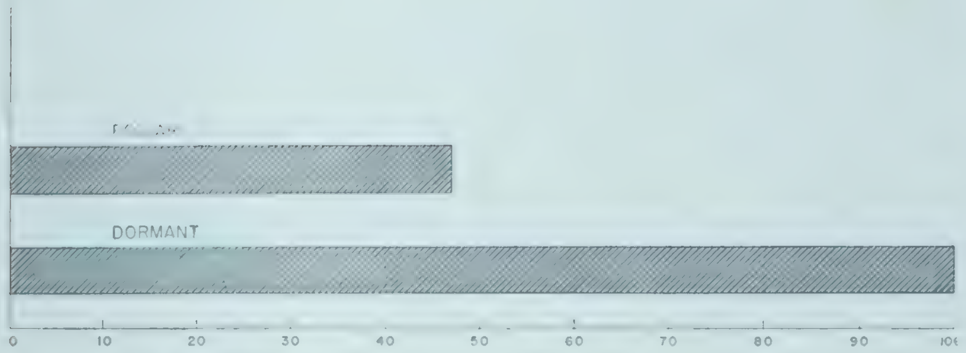


Figure 16. Relative DDT deposit obtained on twigs when a 70-foot elm was treated with a mist blower in the summer and in the dormant period using one gallon of 12 per cent DDT emulsion. The dormant deposit rating is 100 while the summer deposit was only 47 per cent as great.

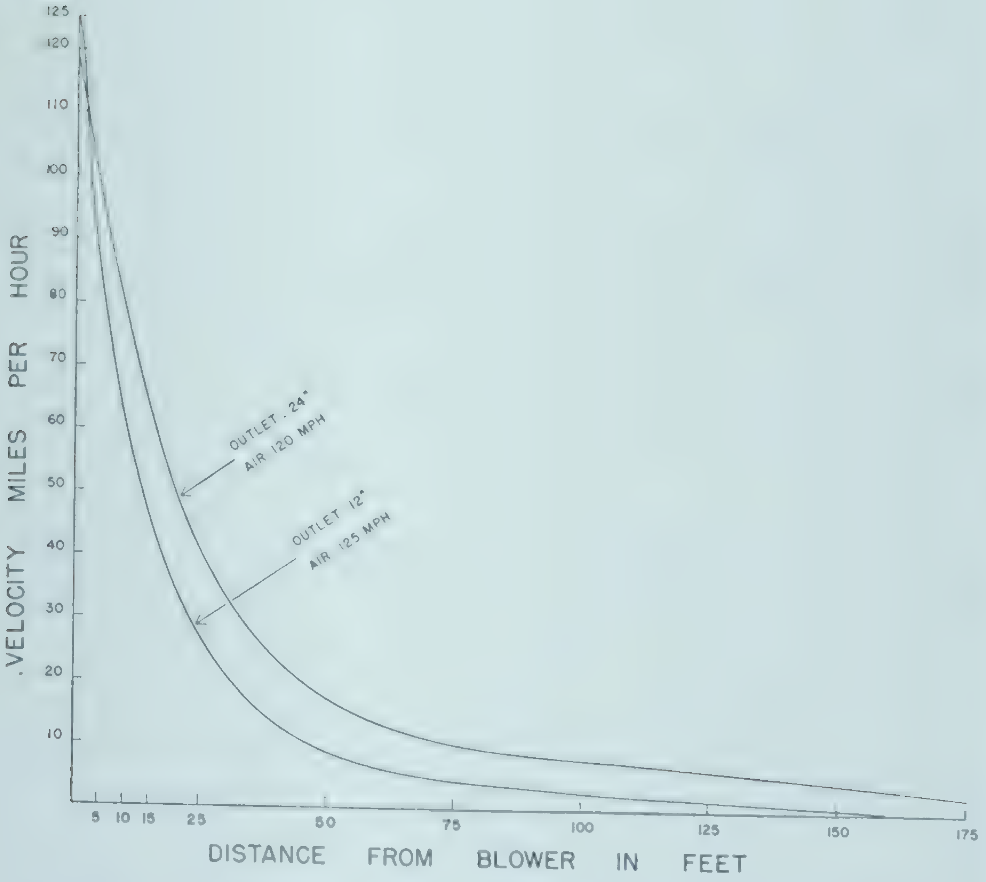


Figure 17. Air velocity at given distances from two blowers with one discharging air at 125 mph through a 12-inch diameter outlet, and the other one delivering it at 120 mph through a 24-inch outlet.

position one and the center of the tree, position three is in the center of the canopy, position four is half way between the center and the outer leaves of the far side, and position five is at the far side of the tree from the blower.

Table 24 shows the deposit resulting when the same mixture was applied with a 6 h.p. mist blower traveling one m.p.h. using a 5-inch diameter round outlet delivering 1500 c.f.m. of air.

Under similar wind conditions 97 per cent more mist spray deposited on ⅛ to ⅜ inch twigs of 30-foot Norway maples in the dormant season than for the same amount of spray applied in the foliar season. In a 70-foot elm tree, a given quantity of mist spray gave 100 micrograms of insecticide deposit per unit area of glass slides in the dormant season as compared with 47 micrograms per unit area when the foliage was fully developed (Figure 16). A comparison of the twig deposit on dormant elms applied by hydraulic sprayers or by mist blowers is given in Table 25.

When applying an emulsion in the dormant season, the mist blower deposited 83 per cent more insecticide per gram of Norway maple twigs than the hydraulic sprayer. During the foliar period the concentrate sprayer deposited only 27 per cent more insecticide per gram of twigs than the hydraulic sprayer. The distribution in the top centers of fully foliated Norway maples was only slightly better in trees sprayed with a hydraulic sprayer than in mist blown trees. The data emphasizes the fact that in the dormant season, at least, less material is required when using mist blowers to obtain a given deposit than with hydraulic sprayers.

In commercial applications to large orchards of big, tall or dense trees, it is necessary to have a fine spray of 35 to 60 microns average diameter driven with sufficient air velocity and volume to impinge a high percentage of the drops through at least half the crown of the tree from two opposite sides. The air velocity needed depends primarily on the velocity required for sufficient spray atomization with available pump pressure. The air volume needed depends primarily on (1) the height, diameter, and density of the tree crowns, and (2) the rate of travel of the spray machine (Figure 17). The volume of air needed is roughly in proportion to the rate of travel. In this connection the design of the outlet must be such as to throw a soft, widely spread air-spray stream to the lower part of the tree close to the machine and an air stream of higher velocity to the tree tops. Spray should be driven across the top of the tree from a higher position on the machine than for the lower part of the tree. The average drop size for spray going to the lower part of the tree should be 35 to 40 microns as compared with 55 to 60 microns for the tops of trees 20 feet or more in height.

Table 26 shows the drop size at different levels when deliver-

Table 26. Drop size on slides at different elevations in an elm tree when delivering air at 126 m.p.h. velocity through a 12 inch diameter outlet, and spray delivery at 40 p.s.i. through four No. 1 Whirljet nozzles and one, No. 10 Whirljet nozzle.

Feet from ground	Average drop diameter for:		Range in drop diameter for:	
	No. 1 Whirljet nozzles	No. 10 Whirljet nozzles	No. 1 Whirljet nozzles	No. 10 Whirljet nozzles
	microns	microns	microns	microns
20	42	106	8 to 140	20 to 475
25	40	102	8 to 140	20 to 450
30	38	94	8 to 140	20 to 430
35	42	88	10 to 140	20 to 410
40	46	82	10 to 140	20 to 380
45	50	81	12 to 135	20 to 350
50	53	77	12 to 135	20 to 300
55	56	74	12 to 135	20 to 275
60	57	76	14 to 130	20 to 240
65	60	80	14 to 130	20 to 220
70	61	78	16 to 125	20 to 175

Table 27. The DDT deposit and drop size of spray solutions at four elevation levels and for four different directions from the mist blower.

Feet from ground	Percentage of DDT deposit on slides facing different directions				Average drop diameter on slides facing different directions			
	west	east	north	south	west	east	north	south
25	48	10	17	25	39	51	45	44
35	40	13	20	22	38	53	48	45
50	45	10	20	25	50	60	54	54
70	36	15	22	27	60	62	70	65

ing an oil solution of 36 seconds Saybolt (U. V.) through four No. 1 whirljet nozzles and through one No. 10 Whirljet nozzle. At 40 p.s.i. the No. 1 nozzles deliver 0.2 g.p.m. per nozzle and the No. 10 nozzles deliver 2 g.p.m. Air was delivered at 125 m.p.h. through a 12-inch diameter outlet. Drop size samples were taken from the air stream at 50 feet from the machine. Measurements gave a numerical average drop diameter of 41 microns for the No. 1 nozzles and 86 microns for the No. 10 nozzles. When samples were trapped and allowed to settle, the average drop size was 36 microns for the No. 1 nozzles as compared with no noticeable change for the No. 10 nozzle. Two gallons of mixture were applied in each test.

The No. 10 nozzle was in the center of the outlet and pointed with the air blast to give a minimum of spray atomization and loss of spray from the air stream. The No. 1 nozzles were equally spaced four inches from the center of the outlet, and were pointed against the air blast.

The data show a reverse drop size deposit relationship with elevation of the two nozzle sizes. This is due to the fact that the high air velocity close to the machine impinged a large proportion of the small droplets as well as the large ones, whereas in case of the large nozzle many large drops drift out of the air stream before reaching the higher levels. A high proportion of the large drops that reached the 55 to 70 foot level apparently deposited on the slides, whereas most of the small drops did not impinge on the slides. The range in drop size from the two nozzles is given in the last two columns of Table 26.

Table 27 shows the average drop size and the percentage of spray deposited on four different sides from the blower. In these tests, the blower traveled slowly (0 to 1 m.p.h.) in a straight line that came to within 5 feet of the tree trunk. The slides on the side facing the blower receive the heaviest deposit, and are listed in the Table under "W". Slides opposite the blower (E) received the least deposit. The spray was applied through four No. 1 Whirljet nozzles at 50 pounds pressure. The data are based on five replications.

When applications were made with the mist sprayer 25 to 50 feet from the tree trunk, the deposit was not as evenly distributed in all four directions, as the slides facing the blower received a greater portion of the total deposit.

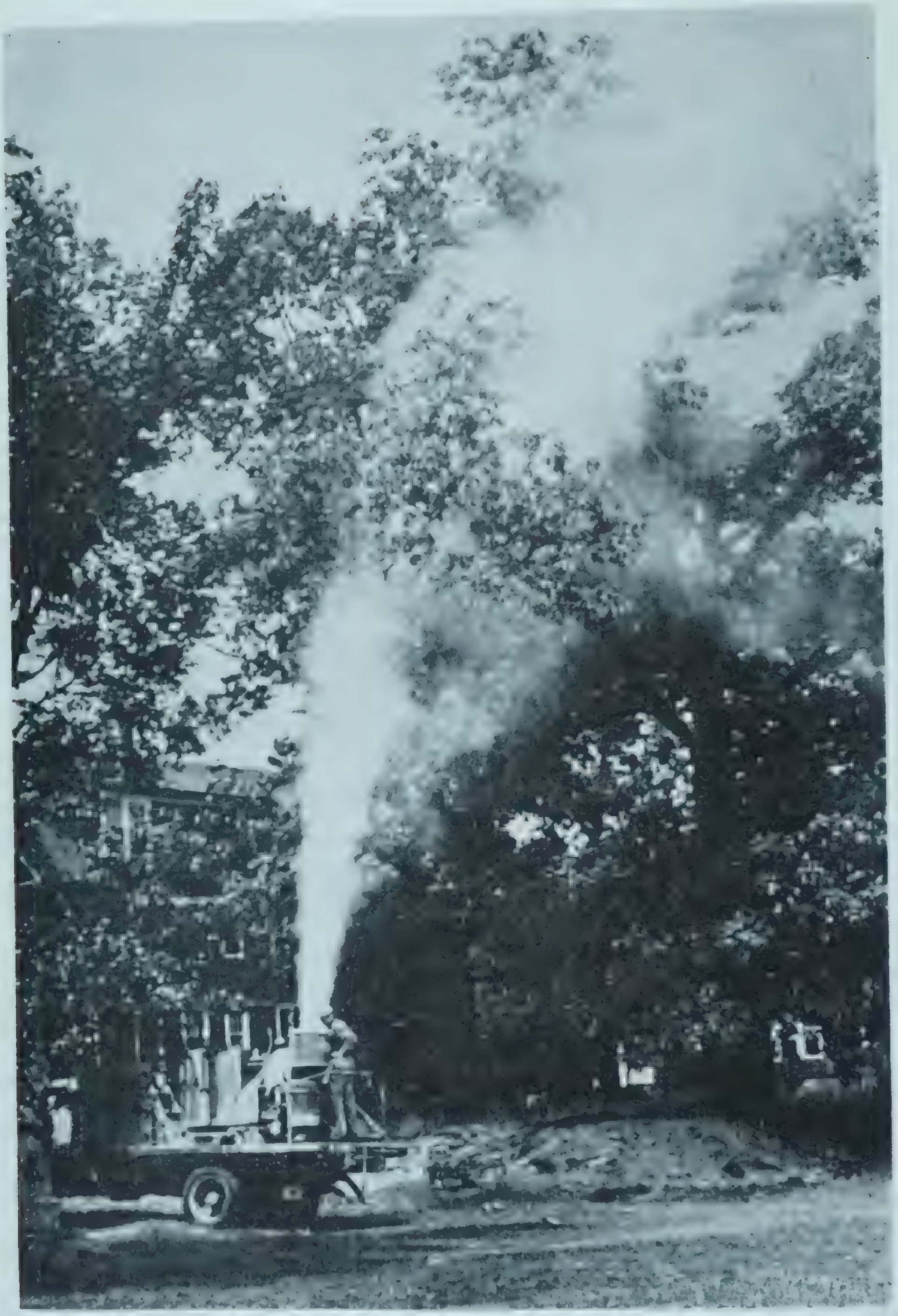


Figure 18. Twenty-five horsepower blower-atomizer treating an 80-foot red oak at Yale Bowl New Haven, Conn. Machine was equipped to apply dust, aerosol, spray-dust, and atomized concentrates. Nozzle assembly is such as to fill the air stream. The large outlet and velocity control makes possible a wide spray stream. A small amount of dust was added to facilitate photographing

Potts, Garman, Friend, and Spencer, 1950.

Coverage

POTTS, Garman, Friend, and Spencer (1950) point out that: "The mist from a blower rises best on calm, warm, dry, sunny days, when there is some upward air current. Height is most difficult to attain on cold, damp, cloudy, windy days. High wind is the most important deterrent to mist blower application, and complete coverage of tall shade trees should not be attempted with winds greater than five miles per hour. On the other hand, certain types of application, such as mosquito control, are favored by light winds which carry the tiny droplets to great distances (often 500 to 1,000 feet) from the applicator. In the latter type of application, most of the spray is directed practically straight up into the air to increase the distance that some of it will drift before falling to the ground." The possible drift of small drops is indicated by the data given by Potts (1946): "A droplet 100 microns in diameter and having a specific gravity of 1.0 will drift while falling 50 feet in air moving parallel to the ground at various speeds as follows:

Miles per hour	*Feet*
0.25	22
0.5	45
1	87
2	175
3	265
4	348
5	435
10	765

It should be realized, of course, that a drop of water will evaporate fairly rapidly, but this may mean it will drift farther if it gets much smaller. Any change in specific gravity would modify this somewhat."

Rate of travel affects coverage. In treating for mosquitoes, flea beetles, leaf hoppers, and gross feeders like the gypsy moth, cankerworms, tent caterpillars, tussock moth and fall webworm, a rate of travel of approximately two m.p.h. for swaths of 50 to 100 feet can usually be maintained. Treating for the elm leaf beetle and certain other pests requires better tree top coverage on the undersides of the leaves and, therefore, a slower travel rate.

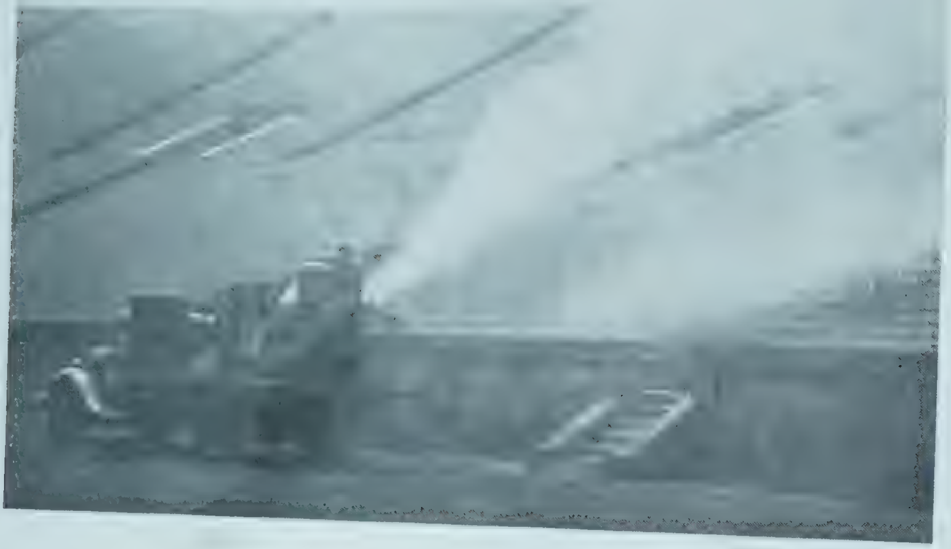
Tree Coverage

TO cover tall trees and other areas rapidly, and to dispense and spread properly a large output of spray, while traveling 1.5 to 3 m.p.h., it is necessary to deliver a large volume of air at optimum velocity.

It is important to give special attention to the tree tops. Even though the top of a 70-foot tree may appear to be well covered, the deposit often is three to six times as great 30 to 40 feet from the ground as at 70 feet. To achieve the required coverage of small, relatively fixed disease spores, aphids, lace bugs, mites, mealybugs and scale insects, it is necessary to cover completely all parts of the tree, particularly the top. This often requires a slow rate of travel and frequent stopping and starting. Since the spray rises to greater heights when released under the canopy of trees or woodlands than when released in the open, open grown trees may require more time and spray material per given ground or foliage area than closed stands.

Figure 19. Twenty-five horsepower blower-atomizer treating interior of Yale Bowl for control of mosquitoes. The blower and outlet can be turned in a 180 degree arc for spraying up or down.

Potts, Garman, Friend, and Spencer, 1950.



Tests were made to determine the relative DDT deposit on 1 x 3-inch glass slides suspended in a vertical position at 5-foot intervals along a rope from the top of a 70-foot elm tree to a distance of 20 feet from the ground (Table 28). Deposits obtained in these tests may be compared with those obtained on twigs of elms sprayed with a mist blower and with a hydraulic sprayer. Due to the vertical position of the glass slides (Table 19) and to their greater surface area, the deposit on them was not as great per given area as on small twigs at the tree top. The wind conditions for Table 15 approximate those for column 2 of Table 28. With favorable conditions, the mist blower gives a higher deposit than the hydraulic sprayers used in shade tree work.

Greatest height is attained by allowing the machine to stand under the tree for a few seconds with the air directed to the tree top at full blast (Table 29). As soon as the air stream reaches the tree top in sufficient force to move the branches or foliage noticeably, spray is released by opening a conveniently located, quick acting shut off valve. After closing this valve, the air from

Table 28. Relative DDT deposit on 1 x 3-inch glass slides suspended in a 70-foot elm at given heights from ground with mist blower delivering 8,000 c.f.m. of air at 125 m.p.h. through a 12-inch diameter outlet.*

From Potts, Garman, Friend, and Spencer (1950)

Feet from ground	Average relative deposit** of 16 experiments with winds of 0.5 to 8 m.p.h. (40 feet = 100)	Average relative deposit of 5 experiments with no wind movement (conditions ideal)
20	153	150
25	188	175
30	173	184
35	128	136
40	100	125
45	75	110
50	49	76
55	28	56
60	14	34
65	11	28
70	6	17

* Analysis by R. D. Chisholm and Louis Koblitsky.

** To find the deposit in micrograms per square inch of surface, multiply the figures in column 2 and 3 by 4.379.

Table 29. Seconds required for air stream to reach given heights when delivered at 125 m.p.h. through a 12-inch diameter outlet pointed vertically.

From Potts, Garman, Friend, and Spencer (1950)

Height from outlet feet	Diameter of air stream (approximate)	Seconds to reach given height in calm air	Seconds to reach given height in 5 m.p.h. wind
25	11	1	1.5
50	18	3	5
75	23	8	25 (max. hgt.)
100	35	14	—

Figure 20. A dual nozzle outlet with a ring of four adjustable direction, fine-spray atomizing nozzles pointing at right angles to the blast; and a coarse, pyramid-shaped solid stream nozzle in the center of the outlet. The two systems are operated by two separate shut-off valves.

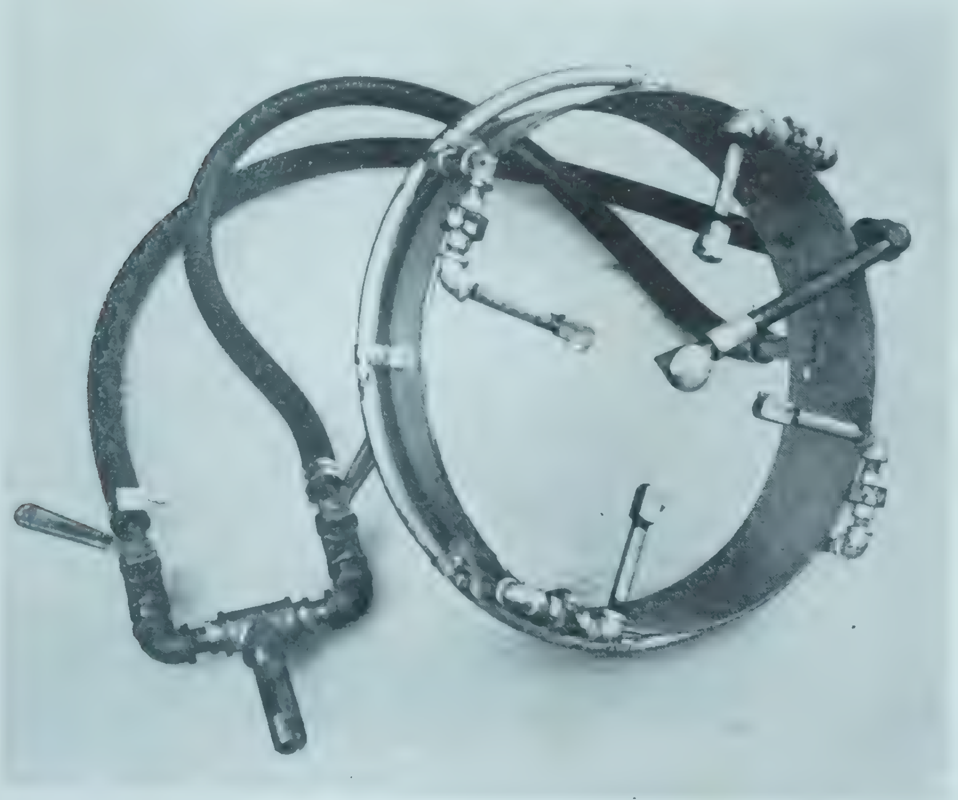


Table 30. DDT deposit from emulsions on 1 x 3 inch slides in a 70 foot elm tree when using 3 nozzle sizes.

Feet from ground	Percentage of total above ground deposit for: No. 1 Whirljet nozzles	No. 10 Whirljet nozzle	Dual nozzle system of No. 1 and No. 5 nozzles.
20	15.	18.	15.
25	16.	18.	14.
30	15.	20.	14.
35	14.	13.	13.
40	14.	12.	11.
45	11.	8.	10.
50	7.	6.	7.5
55	5.	4.	6.5
60	1.5	1.3	3.5
65	1.0	1.0	2.5
70	0.5	0.7	2.0
Total			
Ground*	none	10.0**	trace

* Average deposit from 30 slides on ground under canopy.
** Ten per cent of the total above ground deposit on 44 slides.

Table 31. Rate of coverage for given rates of travel and for given widths of swath*

Rate of travel of machine m.p.h.	Feet traveled per hour	Feet traveled per min.	Acreage covered per hour for strips of: 12.5′	25′	50′	100′	200′	300′	500′
0.5	2,640	44	0.75	1.5	3	6	12	18	30
1.0	5,280	88	1.5	3.0	6	12	24	36	60
1.5	7,920	132	2.3	4.5	9	18	36	54	90
2.0	10,560	176	3.0	6.0	12	24	48	72	120
3.0	15,840	264	4.5	9.0	18	36	72	109	180
4.0	21,120	352	6.0	12.0	24	48	96	145	240
5.0	26,400	440	7.5	15.0	30	60	121	181	302
10.0	52,800	880	15.0	30.0	60	120	242	362	604

* To calculate the combined nozzle output required per hour. multiply the acres covered per hour by the number of gallons to be applied per acre.

Table 32. Actual spraying time required to apply given quantities of spray concentrate at given rates of delivery.

Quantity of solution	Time required to spray the quantity listed in Column 1 at the following delivery in gallons per hour										
	5	10	15	20	30	45	60	90	120	180	240
2 ozs.	11.3 sec.	5.6 sec.	3.8 sec.	2.8 sec.	1.9 sec.	1.3 sec.	0.9 sec.	0.6 sec.	0.5 sec.	0.3 sec.	0.2 sec.
4	22.5	11.2	7.5	5.6	3.8	2.5	1.9	1.3	0.9	0.6	0.5
8	45.0	22.5	15.0	11.3	7.5	5.0	3.8	2.5	1.9	1.3	0.9
1 pint	1.5 min.	45.0	30.0	22.5	15.0	10.0	7.5	5.0	3.8	2.5	1.9
2	3.0	1.5 min.	1.0 min.	45.0	30.0	20.0	15.0	10.0	7.5	5.0	3.8
3	4.5	2.3	1.5	1.1 min.	45.0	30.0	22.5	15.0	11.3	7.5	5.6
4	6.0	3.0	2.0	1.5	1.0 min.	40.0	30.0	20.0	15.0	10.0	7.5
6	9.0	4.5	3.0	2.3	1.5	1.0 min.	45.0	30.0	23.0	15.0	11.5
1 gal.	12.0	6.0	4.0	3.0	2.0	1.3	1.0 min.	40.0	30.0	20.0	15.0
1.5	18.0	9.0	6.0	4.5	3.0	2.0	1.5	1.0 min.	45.0	30.0	22.5
2.0	24.0	12.0	8.0	6.0	4.0	2.7	2.0	1.3	1.0 min.	40.0	30.0
3.0	36.0	18.0	12.0	9.0	6.0	4.0	3.0	2.0	1.5	1.0 min.	45.0
5.0	60.0	30.0	20.0	15.0	10.0	6.7	5.0	3.3	2.5	1.7	1.3 min.
10.0	120.0	60.0	40.0	30.0	20.0	13.3	10.0	6.7	5.0	3.3	2.5
15.0	180.0	90.0	60.0	45.0	30.0	20.0	15.0	10.0	7.5	5.0	3.8
30.0	360.0	180.0	120.0	90.0	60.0	40.0	30.0	20.0	15.0	10.0	7.5

From Potts, Garman, Friend, and Spencer (1950) the fan is allowed to continue to the spot that has just been sprayed for several seconds before changing direction of the outlet (air blast). This prevents the mist from falling back. This procedure requires more time and often more spray volume than continuous travel. Injecting dust in the air stream is often a useful means of determining wind direction and velocity visually, as well as their effect on distance or height attained by the air stream.

Dual Nozzle System for Tall Trees

A WIDE spray stream of fine spray of 35 to 45 microns drop diameter is ideal for treating the lower tree crown and other objects when there is sufficient air velocity to impinge the tiny droplets. By the time the air stream reaches the tops of tall trees, however, its speed has been so diminished as not to impinge enough of the small droplets. At this point, larger drops (60 to 80 microns diameter) are needed to effect impingement on the tree bark and foliage.

This problem has been at least partially remedied by installing a dual nozzle system, whereby the lower portion of the tree near the mist blower can be treated with a fine spray to effect maximum coverage and distribution, and a minimum of foliage injury; while the upper portion of the tree crown can be treated with a coarser spray to increase deposit at high elevations. The system can be adapted to various mist blowers (Figure 20).

Range in air velocity and volume limits the use of a coarse spray nozzle in the dual nozzle system. It determines the orifice size, pressure, and type of nozzle to install. If velocity and volume are too low, the large drops will fall out of the air stream too quickly. On the other hand, if the velocity is too high, i.e., above 125 m.p.h., provision must be made to prevent too fine atomization by the shearing action of the air stream. For the high velocity rigs, it is necessary to use a coarsely atomizing nozzle. This can be either a cone type nozzle (as Whirljet No. 5 or No. 10), or a solid stream nozzle with three 1/16-inch orifices, or with three 5/64-inch orifices.

Spray streams from the orifices should leave the nozzle at an angle of about 35 degrees from the line of direction of the air blast. If the angle is too great the spray may break out of the air stream. If it is too narrow the spray may concentrate in the center of the air stream. The coarse nozzle should be located in the center of the outlet and pointed with the air blast. The pump pressure should be kept under 50 pounds. The output of this nozzle should approximate that for the combined ring of finely atomizing nozzles. The two sets of nozzles are not used to inject spray into the air stream simultaneously. To spray with one set of nozzles at a time, two shut-off valves may be used—one for each system. Hence, the operator simply uses one quick acting shut-off valve to turn the spray on and off for the ring of finely atomizing nozzles, and another similar type of valve to turn the spray on and off to the single, coarse spray nozzle. A more simplified method for operating the two nozzle systems may be to install a three-way valve that can be operated with a single lever.

Machines that deliver 95 to 110 m.p.h. air velocity at 17,000 to 24,000 c.f.m. of air are well suited for carrying the large droplets to the tops of tall trees, provided that they have a means of delivering a *finer* spray to the lower portion of the trees than to the tops of tall ones; and provided atomizing nozzles are in both systems.

Table 30 shows the percentage of DDT deposit at given levels for (1) a ring of four, No. 1 Whirljet nozzles, (2) a No. 10 Whirljet nozzle, and (3) a dual nozzle spray wherein the lower portion of the crown was treated with a fine spray from a ring of four No. 1 Whirljet nozzles while the tree top received a coarser spray (60 to 70 microns average diameter) from one, No. 5 Whirljet nozzle located in the center of the outlet. These data indicate that the dual nozzle arrangement deposited about twice as much spray in the upper 20 feet of crown as the No. 1 and No. 10 nozzles. The total deposit for the dual nozzle arrangement and the No. 10 nozzle was 8 per cent and 12 per cent greater than for the No. 1 nozzles alone. There was a noticeable light ground deposit from the No. 10 nozzle due to some of the large drops falling out of the air stream.

Swath or Strip Coverage

THE width of the swath that can be covered depends on the insecticide, size of drops, the wind direction and velocity, the terrain, the air volume and velocity of the machine and its rate of travel (Table 31). The effective swath width may also depend on the kind of insect to be controlled.

In swath or strip coverage, by far the greatest portion of the spray must be directed towards the border of the strip farthest from the blower, since the largest drops and the greatest number of drops have a tendency to deposit near the machine.

Rate of Coverage and Nozzle Spray Delivery

THE rates of coverage (acres per hour) for given rates of travel when treating swaths of given widths are given in Table 31. Tables 32, 33, and 34 list the time required to discharge given volumes of spray mixture through nozzles or nozzle assemblies delivering given quantities of water per hour. Thus, from these tables the actual spraying time required to deliver specified volumes of spray liquid per tree, per unit area, or per acre can be found.

Table 33. Gallons of water delivered per nozzle per hour with several whirljet nozzle sizes*

Nozzle No.**		Diameter of orifice inch	Gallons delivered per hour at the following pressures (pounds):						
Conn.	Conn.		10	20	30	40	60	80	100
A1	B1	1/16	6.0	8.4	10.0	12.0	14.4	16.8	18.6
A2	B2	5/64	12.0	16.8	20.0	24.0	28.8	33.6	37.8
A3	B3	3/32	18.0	25.0	30.0	36.0	43.2	50.4	56.4
A5	B5	1/8	30.0	42.0	51.6	60.0	72.0	84.0	96.0

* Data of Spraying Systems Co., 4021 West Lake St., Chicago, Ill.

** Nozzles can be obtained for 1/8-inch or 1/4-inch pipe connections. Specify hardened steel nozzles instead of brass. In the whirljet nozzles the inlet port hole is slightly smaller than the nozzle orifice.

Table 34. Gallons of water delivered per minute through orifices, tubes, or jets of given diameter at given pressures per square inch.

p.s.i.	Diameter of orifice or jet (inches)						
	3/8	1/4	1/8	3/32	1/16	1/32	1/64
700	67.5	30.0	7.5	4.7	2.0	0.5	0.12
175	33.7	15.0	3.7	2.3	1.0	0.25	0.06
44	16.8	7.5	1.8	1.2	0.5	0.12	0.03
11	8.4	3.7	0.9	0.6	0.25	0.06	0.01
3	4.3	2.0	0.5	0.3	0.1	0.02	No flow

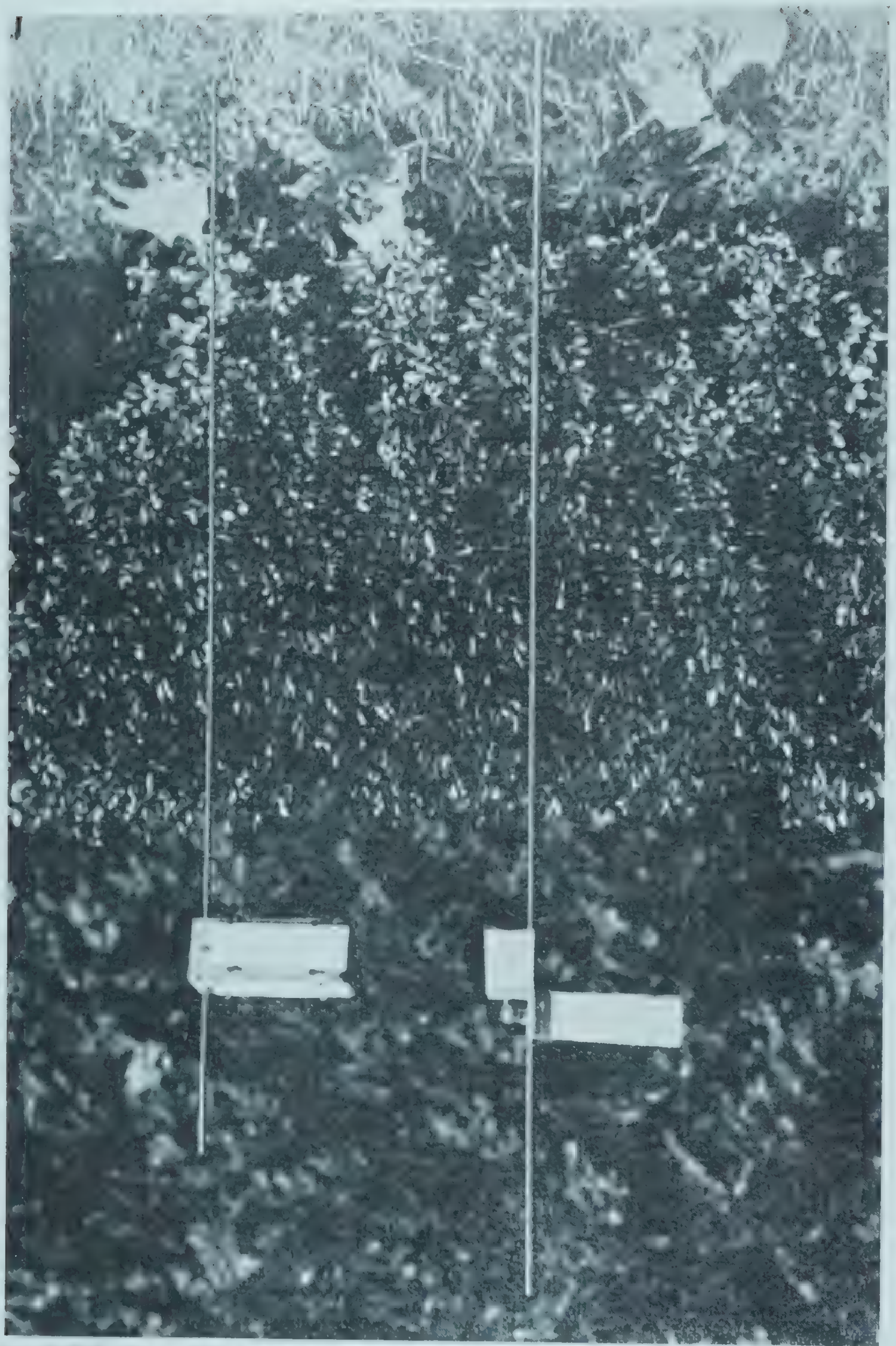


Figure 21 Deposit slides and other objects suspended at given elevations and positions in growth five feet or less in height The slide holders may be moved up or down the 5-foot rods. Paper clips cover the face of the slide that is not to be exposed.

Deposit Distribution on Low Growing Vegetation

APPLICATION to low growing vegetation requires different apparatus and application technique than is required for trees. The foliage is compact, close to the ground, and the discharge nozzles are generally above the foliage canopy. Good distribution and deposition from top to bottom of plant and on the undersides of the leaves is of utmost importance. This necessitates an air blast and fine atomization for best penetration and distribution.

To study deposition and distribution on low growing vegetation, a medium dense weed field was treated with a mixture containing per gallon: 1½ pounds of lead arsenate, 8 ounces of S.A.E. 10 motor oil, 1/3 ounces of Triton X-100, and 7 pints of water, using a Homelite mist blower. Application was made with the triple round outlet mounted five feet above ground and pointing toward the latter at a 15 degree angle. The average drop size was 48 to 52 microns. Single tests consisted of three replicates. In each replicate there were five 1 x 3 inch glass slides for each of seven positions. They were spaced three feet apart across the width of the swath on metal rods (Figure 21). The seven different positions exposed were: (1) upper surface (2) lower surface (3) diagonal position, upper surface (4) diagonal position, lower surface (5) vertical position with slide facing at right angles to the air blast (6) front (flat) side of vertical slide facing blower. and (7) back side of vertical slide (opposite position to No. 6. (Figures 22 and 23).

In test No. 1 (Table 35) the slides were placed in a weed field. In test No. 2 they were completely exposed on an open field. The deposit figure in the table is the average number of micrograms of lead arsenate per slide. The deposit rating for any position is a percentage figure obtained by dividing the deposit for the position of heaviest deposit into the deposit for that position. Hence, the position with heaviest deposit is given a rating of 100 and all other positions rate a percentage of 100. The average size of drops deposited at each of the different positions is also listed in the tabulation. The deposit in the weed stand was only 46.5 per cent as great as for the open field due to the screening effect of the foliage.

The relative merits of the Homelite mist blower, low gallonage non-blower, boom sprayer, and hydraulic sprayer were compared

Table 35. Deposition of spray on slides in various positions in low growing vegetation, and in the open at 14 inches above ground using a row crop mist blower. Deposit is in micrograms of lead arsenate per 3 x 3 inch slide.

Test number and description	Position of deposit and slide						
	1 Upper surface, horizontal	2 Lower surface, horizontal	3 Upper surface, diagonal	4 Lower surface, diagonal	5 At right angles to air blast, vertical	6 Flat face of vertical slide facing blower	7 Back side of vertical slide opposite blower; reverse of No. 6
	Micrograms						
Test No. 1 with slides in weed stand	646	71	425	210	322	364	78
Rating for Test No. 1	100	11	66	32	50	56	13
Test No. 2 with slides in open	964	140	810	400	650	1400	190
Rating for Test No. 2	68	10	58	29	46	100	14
Average drop diameter at each position, in open	63	42	45	40	46	48	65

for their relative ability to distribute insecticide deposit from top to bottom of a medium dense weed growth 28 inches in height. For each of the three methods, the same quantity of lead arsenate was applied per unit area. The gallonge rates per acre for the mist blower, low gallonage boom, and hydraulic sprayer were 6, 6, and 200 gallons, respectively. For each of these three tests there were 20 horiontal slides at each of four different sampling levels. The sampling levels were 6, 12, 18, and 24 inches above ground.

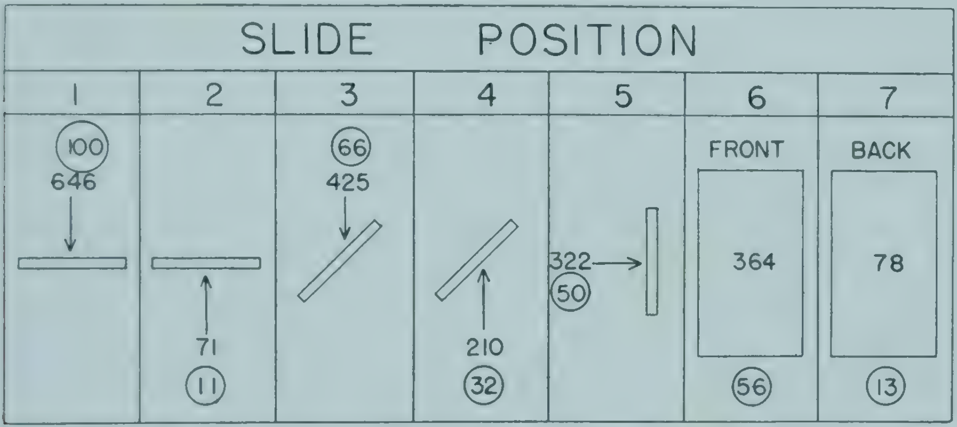

SLIDE POSITION
1
2
3
4
5
6
7
100
646
71
11
66
425
210
32
322
50
FRONT
364
56
BACK
78
13

Figure 22. Deposit in micrograms per 1 x 3-inch slide (not circled) and the percentage rating (in circle) for each position in Test No. 1.

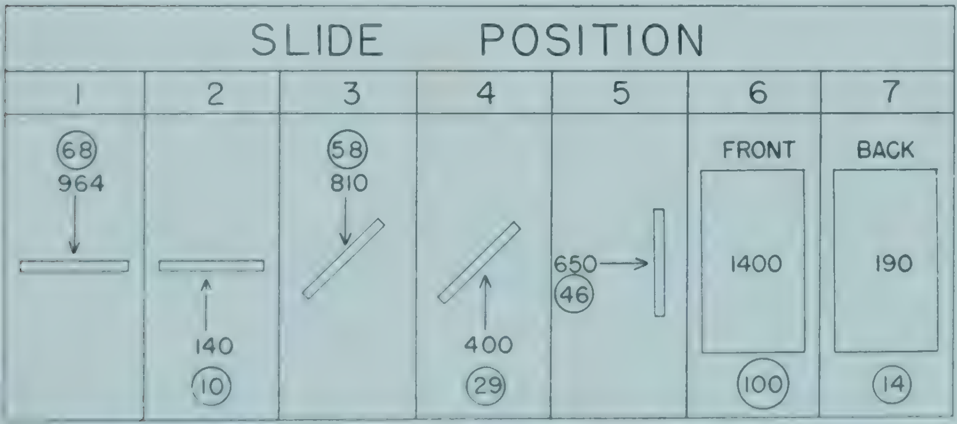

SLIDE POSITION
1
2
3
4
5
6
7
68
964
140
10
58
810
400
29
650
46
FRONT
1400
100
BACK
190
14

Figure 23 Test No. 2 Arrow points to face of slide that was analyzed

Table 36 gives the deposit in micrograms per square inch at each sampling level for each method.

Table 36. Deposit in micrograms per square inch by 3 methods of application on slides placed at 4 different levels in a weed stand.

Height from ground, inches	Kind of Applicator: Mist blower	Low gallonage non-blower concentrate sprayer	Hydraulic sprayer
	micrograms	micrograms	micrograms
24	525	710	280
18	505	520	380
12	400	210	320
6	280	135	360
Total	1710	1575	1340

The mist blower deposit was heavier than for other methods but was not quite as even in distribution from top to bottom of the plant as for the hydraulic method. The mist-blown deposit on the under sides of the leaves was at least as heavy as for the hydraulic method. The low gallonage boom gave the poorest distribution from top to bottom of plant and the lowest deposit on the under sides of the leaves.

Frequent On-Farm Calibration of Spray Machinery Needed

FREQUENT checking or calibration of spray equipment by the operator on the farm offers the only accurate and practical way of applying correct amounts of insecticides and herbicides to weeds and crops. Wear on the many parts of the sprayer, the speed at which spraying is done, and the care taken in mixing the chemicals with water, all cause variations in spraying rates that can seriously affect spraying results.

Two ways of calibration suggested are: (1) Select the gallonage of mixed spray that is required per acre, and then, by trial and error, adjust the tractor speed and pump pressure to get this dispersal; (2)

Select a convenient tractor speed and pump pressure and then see how much spray is applied per acre. With this knowledge, mix chemicals and water to get the spray concentration required.

One of two things generally happens if applicators follow the spray rate tables furnished them with their sprayers, rather than calibrating their machines before starting to work. In the first case, they put on too much spray, which not only wastes insecticides or herbicides, but, if they are spraying weeds growing among sensitive crops, may also kill both weeds and crops. The second possibility is that too little spray may be applied, resulting in poor weed or insect control, which means wasted pesticide, time, and money in operation of the spray equipment.

Manufacturers' recommended spray rates, accurately arrived at in tests with laboratory equipment, may not apply as completely when the farmer hooks the sprayer on behind his tractor and moves into the field. Tractor speed is one of the important factors in correct spray application. Unless the tractor is equipped with a speed indicator, it is hard to do more than approximate the rate of speed. Errors are, thus, introduced that only calibration by the operator will correct. The tractor power take-off speed, which in many instances drives the sprayer pump, can vary as the engine revolutions per minute fluctuate, changing the sprayer pressure—another important spray-rate factor.

As parts become worn, the pump of the sprayer will continue to supply spray but at fluctuating pressures. These variations in pressure, developed by a worn or dirty pump, can change the amount of spray put out from day to day, or in severe cases, from hour to hour.

Strainers and nozzle screens of the sprayer often become partially clogged, reducing the amount of spray that can pass through. The nozzles, themselves, although carefully machined by the manufacturer to supply certain quantities of spray at certain pressures, offer another source of variation as they wear or become plugged. The rough treatment that the sprayer pressure gauge gets in field operation can also damage it so that it will read inaccurately.

Even though the sprayer is calibrated, the causes of variation are still present. To do a good, safe job of spraying, it is necessary continually to check the operation and rate of application of the sprayer.

A swath 100 inches wide and one mile long is one acre, and a swath 100 feet wide and one mile long is 12 acres. Acres per hour, then, are determined by multiplying the swath width in inches by the speed of the tractor in miles per hour and dividing by 100.

$$\frac{\text{Swath width (inches) x mph}}{100} = \text{acres per hour}$$

The gallons per acre can now be determined by dividing the gallons per hour by the acres per hour. The complete formula is then:—

$$\frac{\text{gph}}{\dfrac{\text{Swath width (inches) x mph}}{100}} = \text{gallons per acre}$$

Example: If the average output of the spray rig is .72-gallon in 6 minutes with 4-row equipment cultivating 40-inch rows at 3 m.p.h., then:—

$$\frac{0.72 \text{ x } 10}{\dfrac{160 \text{ x } 3}{100}} = \frac{7.2}{4.8} = 1.5 \text{ gallons per acre}$$

A vehicle traveling 4 m.p.h. (352 feet per minute or 4 x 88) down 36 inch rows will treat 1.43 acres per hour for each row covered, or 1.7 acres per 42 inch row covered.

$$\text{g.p.m./nozzle} = \frac{\text{Row spacing in inches x gals./acre x mph}}{\text{Nozzles per row x 5940}}$$

As an example, with 34-inch row spacing, using three nozzles per row and traveling 4 m.p.h., 0.19 gallons per minute is required from each nozzle to apply 25 gallons per acre. That is:

$$0.19 = \frac{34 \text{ x } 25 \text{ x } 4}{3 \text{ x } 5940}$$

One procedure for setting the sprayer to deliver the desired rate is as follows:

1. Set the pressure regulator at some trial position.
2. Collect the discharge from each of several nozzles along different points of the boom for a period of one minute.

3. Average the amount collected from the nozzles and see how it compares with the amount required per nozzle. If amount collected is less than amount required, increase the tension on the pressure regulator, and if more, decrease the tension.
4. Repeat the above procedure until the average amount per nozzle collected on a trial run checks with the amount required.
5. Read the gauge pressure and maintain this pressure when operating.

The liquid collected from each nozzle may be more conveniently weighed than measured. Since a gallon of water weighs 8.34 pounds, the weight of liquid to be collected from each nozzle in the example would be 0.19 x 8.34 or 1.58 pounds.

The following tabulation is another way of presenting coverage data applicable to both cultivator and boom equipment. The figures are in acres covered per mile of travel for swaths of given width. To find the acres covered by a machine, multiply the rate of travel in m.p.h. times the figure for acres per mile.

Width of swath in feet	Acres per mile (5,280 linear feet) *
1	0.121
2	0.242
3	0.363
4	0.484
5	0.605
6	0.726
8	0.968
10	1.210
12	1.452
14	1.694
15	1.815
16	1.936
18	2.178
20	2.420
24	2.904
25	3.025
30	3.630

---

* One mile per hour travel = 88 feet per minute.

Wooten, Smith, and Meek (1950, p. 7) point out that: "In calibrating the machine slight variations in gallonage may be made by adjusting the pressure used. Tractor operating speeds are, in the main, the determining factor in obtaining low gallonage spraying. When spraying with one nozzle per row the gallonage per acre should be from .6 to 1 gallons. With two nozzles the gallonage would be doubled or from 1.2 to 2 gallons per acre. In a like manner, three nozzles per row would require from 1.8 to 3 gallons per acre.

"Careless and inefficient field operations in making the crop may make it difficult, if not impossible, to attain the low gallonage necessary for efficient and economical spray application. Low gallonage spraying is a modern method of cotton insect control and as it is used in conjunction with the cultivating equipment, the cultivation of the crop will require methods and supervision as modern as the spray.

"'In all cases, the rig used should cover the same number of rows which were planted with the planter. A crop planted with a 2-row outfit should be sprayed with a 2-row spray rig. Likewise, 4-row planters can be followed with 4-row spray rigs. It is satisfactory, however, to use a 2-row spray rig where the crop has been planted with a 4-row planter, but 4-row rigs cannot satisfactorily be used in a crop planted with 2-row equipment. It is extremely important that the nozzles be in correct relation to crop row and plants and where the spray machine is wider than the planter; 'guess' rows will cause variations in nozzle location and decrease the efficiency of the operation."

Cotton row widths will vary from 36 to 42 inches in two-inch intervals, with 38 and 40 inches being the most common.

Spray should never be applied in amounts which will result in puddling or run-off from the leaves. Plant injury frequently follows such practice.

On ground equipment, place nozzles so that the terminal and outer leaves of the plants are well covered with spray:

a. One nozzle per row is sufficient for seedling cotton.

b. Use two nozzles per row for cotton 12 to 24 inches high.

c. Three nozzles per row should be used on cotton above 24 inches high, and in irrigated areas as many as five may be used. The nozzle tips should be in sizes to permit delivery

Table 37 showing effect of nozzle size, nozzle position, and aircraft speed on atomization of 5 whirljet nozzles at 40 p.s.i. nozzle pressure.*

Speed of aircraft m.p.h.	Nozzle No.		Diameter of orifice inch	g.p.m. delivery	Mass aver. diameter in microns, with nozzle pointing.		
	Conn.	Conn.			forward	down	aft
60	A1	B1	1/16 (.062)	0.2	110	116	128
	A2	B2	5/64 (.078)	0.4	115	135	160
	A3	B3	3/32 (.093)	0.6	136	165	175
	A5	B5	1/8 (.125)	1.0	152	180	238
	A10	B10	3/32 (.187)	2.0	170	210	276
80	A1	B1	1/16 (.062)	0.2	90	130	158
	A2	B2	5/64 (.078)	0.4	98	138	175
	A3	B3	3/32 (.093)	0.6	110	150	190
	A5	B5	1/8 (.125)	1.0	120	160	225
	A10	B10	3/32 (.187)	2.0	150	210	260
100	A1	A1	1/16 (.062)	0.2	78	100	145
	A2	A2	5/64 (.078)	0.4	88	114	155
	A3	B3	3/32 (.093)	0.6	100	125	165
	A5	B5	1/8 (.125)	1.0	114	152	182
	A10	B10	3/32 (.187)	2.0	130	182	218

* Pump pressure is usually 5 to 10 p.s.i. greater than nozzle pressure. Check valves usually increase pressure about 5 p.s.i.

Table 38. Number of nozzles required for given spray delivery rates.*

g.p.m. per nozzle	Number of nozzles required for the following deliveries in gals./min.							
	5	7.5	10	15	20	25	30	40
0.1	50	75	100	150	200	250	300	400
0.15	33	50	67	100	134	167	200	267
0.2	25	38	50	75	100	225	150	200
0.3	17	25	33	50	67	84	100	134
0.4	12.5	19	25	38	50	113	75	100
0.6	8.3	12.5	17	25	33	42	50	67
0.75	6.7	10.	13.4	20	27	33.4	40	54
0.8	6.25	9.4	12.5	18.8	25	31.3	37.5	50
1.0	5	7.5	10	15	20	25	30	40
1.5	3.3	5.0	6.7	10	13.4	16.7	20	26.7
2.0	2.5	2.5	5.	7.5	10	12.5	15	20
2.5	2.	3.	4.	6.	8.	10.	12.	16.
3.0	—	—	—	5.	7.	8.	10.	13.4

* Pump capacity should be 20% greater than the maximum nozzle output required.

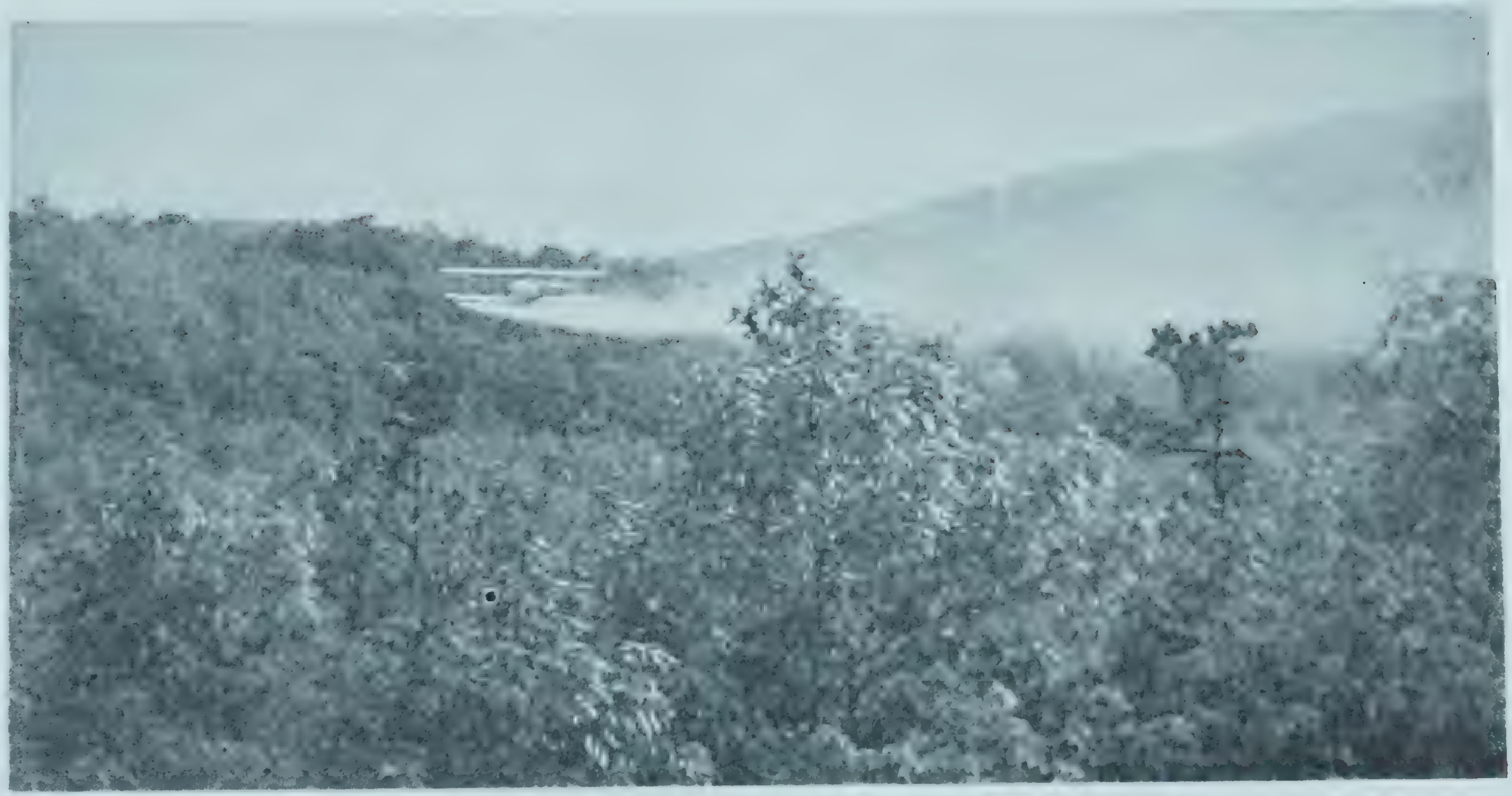


Figure 24. N3N-3 biplane equipped with multiple nozzle spray boom dispersing DDT over gypsy moth infested forest in Pennsylvania.

Courtesy Gypsy Moth Control Project, USDA, ARS.

of 1 to 8 gallons per acre, except in the far west where a greater volume may be required.*

d. To avoid burning of foliage and to obtain better coverage, nozzles should not touch plants. Distance of nozzles from plants will vary from 6 to 12 inches, averaging 10 inches, depending upon equipment, materials used, and weather conditions. Adjust nozzles closer to plants as wind velocity increases.

e. Spraying may be done at wind velocities up to 15 m.p.h.

Spray Pattern, Coverage, and Deposit with Aircraft

Size of Plane

A NUMBER of factors contribute to spray-coverage characteristics and deposit which have a direct bearing on efficiency and effectiveness. The first of these is the size of the plane, its wing expanse and the altitude at which it flies. Small planes and low flying decreases swath width while the reverse condition increases it. For example, cubs normally disperse an effective swath of 32 to 42 feet for crops at an altitude of 2 to 10 feet; or 75 feet when flying 30 to 60 feet above the vegetation, as in spraying forests. In the case of Stearman Biplanes, the normal effective swath width for the 2 to 10-foot flight level is considered to be essentially the same as the wing spread, but this can be altered somewhat by the engine's power, the length of the spray boom and the nozzle arrangement. When spraying forests Stearman planes usually fly 100- to 130-foot swaths, while the DC 3 and B17 multimotored planes fly 500-foot swaths over forests at a flight level of 150 feet above the canopy at a speed of 150 m.p.h.

Atomization

THE degree of atomization is often the most important factor concerned in pest control by aircraft. It influences swath width and pattern, distribution, coverage, deposit, gallonage required per acre, and spray drift. The important factors responsible for a given degree of atomization are (1) the nozzles (their construction, orifice size, position, and direction of discharge), (2) pressure, (3) aircraft speed, (4) air velocity and volume of the propeller slip stream and the relative proportion of spray that is released in the slip stream, and (5) the composition and viscosity of the mixture.

---

* Conference Report on Cotton Insect Research and Control. Memphis, Tenn. 1953.

When releasing the spray at 50 feet or more above forests for defoliators such as sawflies, tent caterpillars, gypsy moths, tussock moths, and spruce budworms a drop pattern with a mass average diameter of 150 microns seems to be about right. If the drops are too small the deposit will be light and much of the spray will be carried up into the upper air currents and drift away from the area being treated. For crop spraying at the 2, 5, 10 and 25-foot levels, a mass average drop diameter of 60, 70, 75 and 100 microns appears to be about right. At the 2- to 10-foot level there is considerable air turbulence in the wake of the plane's passage and slip stream. This turbulence is sufficient to deposit droplets of smaller size than for the 25-foot or greater level, where the effect of turbulence is lost. Also, drift is minimized at the lower flight level. Air turbulence greatly improves under surface coverage and penetration of the vegetation. Hence, with medium fine atomization and low flight, it is possible to control many diseases and insects (aphids, mites, etc.) that could not be controlled as effectively with larger drops delivered at higher flight levels.

The nozzle is the first item to be considered in spray atomization. In Chapters II and III the construction and degree of atomization of various types and sizes of nozzles is given. It remains to be shown precisely what degree of atomization results at given air speeds when the nozzles are placed in predetermined positions in relation to the plane's line of travel. Table 37 gives the degree of atomization from 5 sizes of whirljet nozzles on a biplane traveling at 60, 80, and 100 m.p.h.

In general, most other types of cone nozzles with the same included angle and output give about the same degree of atomization. Flat or fan-shaped spray nozzles do not atomize quite as finely as the cone types.

The finest atomization is produced with nozzles pointing forward, but this may cause some of the spray to collect on the structures of the airplane. If nozzles point to the rear, the atomization is coarse. Therefore, it is usually best to point the nozzles down or slightly forward. Small nozzle orifices, including oil burner nozzle tips, can be used for fine atomization when applying solutions and emulsions, but not for mixtures containing wettable powders which require an orifice of 3/32 inch or greater to avoid clogging. The use of small orifices requires a large number of nozzle tips or nozzle clusters to deliver the desired output. When spraying through finely atomizing nozzles, it is important to have a good 30- to 40-mesh screen between the pump and the nozzles.

Nozzles that deliver the coarsest spray and the most uniform drop size have consisted simply of short hollow tubes pointing aft of the boom.

Increasing or decreasing the pressure increases or decreases the atomization to a lesser degree than a corresponding change in size of orifice or speed of aircraft. Gear pumps can develop considerable pressure, but high pressure requires considerable power which may limit the use of air driven pumps where a high spray output is required.

Increasing or decreasing the speed of the aircraft has a great effect on degree of atomization like increasing or decreasing the air velocity of a mist blower, as shown in Table 37. Some increase or decrease in atomization can be made by changing the viscosity and composition of the spray mixture.

Rate of Coverage by Aircraft

THE acreage covered per hour or per day is governed by the following:

1. Load capacity.
2. Swath width.
3. Gallons-per-acre rate and weight per gallon.
4. Speed of the aircraft.
5. Distance from loading field to treated area (number of trips per hour).
6. Mixing and loading facilities.
7. Length of runs, and whether area is flown both ways or one way.
8. The area—its size, shape, terrain, and obstructions.

A method of estimating acres treated per hour is illustrated by the following example: the effective width of swath for a given plane is 40 feet, and the average speed of flight is 90 m.p.h.

$$\frac{90 \times 5280' \times 40}{43{,}56 \text{ ft}^2 \text{ per acre}} = 436 \text{ acres covered per hour}$$

$$\text{or } 7.3 \text{ acres per minute}$$

In practice the area covered may be much less than 436 acres per hour when time is taken out for loading, fueling, turning at the ends of the area, and traveling back and forth from landing field to treated plot. Consequently, if in one hour: two, 100-gallon-loads are delivered using 4 gallons per acre, the area covered per hour is:

$$\frac{2 \times 100}{4} = 50 \text{ acres.}$$

At ½, 1, 2, 3, 5, and 10 gallons per acre, respectively, the acreage covered per hour would be 400, 200, 100, 66, 40, and 20 acres, respectively. At 3 loads per hour the above figures would increase by 50 per cent, or double in the case of 4 loads per hour.

Spray Delivery, Swath Width, and Coverage Rates

THE spray operator would like to apply the lowest spray volume and the widest swath practical, because per acre costs are often almost directly proportional to gallons-per-acre and swath width. However, some pests require a thorough coverage. This necessitates using a higher gallonage (sometimes 3 to 6 gallons per acre) and 30 to 50 foot swaths that provide considerable overlap.

Also, more spray per acre should be applied on small areas than on big areas because of the greater proportion of spray drift outside of the area on small areas than on big ones.

If it is desired to spray a 40-foot swath at 3 gallons per acre, using a plane with a flight speed of 60 miles per hour, Table 39 indicates that the nozzles must spray 14.5 gallons per minute on the treated swath during the flight. Using 46 nozzles with a capacity of .22 gallons per minute each at 50 pounds per square inch would supply 10.1 gallons per minute, and by adding 10 nozzles, each with a capacity of .44 gallons per minute at this pressure (5 at the outer end of each spray boom) supplying 4.4 more gallons per minute, a total of 14.5 gallons of spray per minute would be obtained. This example is not to be considered as a recommended nozzle arrangement for this swath width and speed, as several other conditions including length of spray boom, flight height, type of airplane, and other factors will influence the correct nozzle placement and type to use in each case.

Swath widths should be conservatively estimated and generally lapped, in order that sufficient material be deposited over the entire sprayed area. The number of nozzles and their size will be governed by the desired application rate, swath width, and speed of flight. Some spray delivery rates in gallons per minute for various application rates for three swath rates and three flight speeds are listed in Table 39. Table 40 gives the same sort of information for larger aircraft.

Table 39. Spray Delivery Requirements in Gallons per Minute for Various Application Rates, Speeds, and Swath Widths for Small aircraft. (From Hedden, 1952).

Flight Speed, Miles per Hour	Gallons per Acre	Required Spray Delivery in Gallons per Minute		
		30 ft. Swath	40 ft. Swath	50 ft. Swath
60	½	1.8	2.4	3.0
60	1	3.6	4.8	6.1
60	2	7.3	9.7	12.1
60	3	10.9	14.5	18.2
60	4	14.5	19.4	24.2
70	½	2.1	2.8	3.5
70	1	4.2	5.7	7.1
70	2	8.5	11.3	14.1
70	3	12.7	17.0	21.2
70	4	17.0	22.6	28.3
80	½	2.4	3.2	4.0
80	1	4.8	6.5	8.1
80	2	9.7	12.9	16.2
80	3	14.5	19.4	24.2
80	4	19.4	25.9	32.3

Calibration

THE calibration problem has been well considered by Yuill, Eaton, and Isler (1951) as follows: "The importance of proper performance in spray equipment cannot be overemphasized. Unfortunately, the methods required for precise evaluations of equipment are too involved for use in the field. However, the tests described below will give a rough estimate of performance and should bring out any serious inadequacies.

"The flow rate, or output, can be determined as follows: (1) Put a measured amount of spray liquid in the tank, (2) have the pilot turn the spray on for a timed interval (30 or 60 seconds) while in straight and level flight at the air speed to be used in the spraying operation, (3) when the plane lands, drain and measure

Table 40. Spray delivery requirements in g.p.m. for various gallonage rates, speeds, and swath widths, particularly applicable to biplanes and various types larger than piper cubs.

Flight speed, m.p.h.	Gals. per acre	Required spray delivery in gallons per minute										
		20 ft. swath	25 ft. swath	30 ft. swath	40 ft. swath	50 ft. swath	60 ft. swath	70 ft. swath	80 ft. swath	100 ft. swath	125 ft. swath	150 ft. swath
60	½	1.2	1.5	1.8	2.4	3.0	3.6	4.2	4.8	6.0	7.5	9.0
60	1	2.4	3.0	3.6	4.8	6.1	7.2	8.4	9.6	12.0	15.	18.0
60	2	4.8	6.1	7.3	9.7	12.1	14.4	16.8	19.2	24.0	30.	36.
60	3	7.2	9.1	10.9	14.5	18.2	21.6	25.2	28.8	36.	45.	54.
60	4	9.6	12.2	14.5	19.4	24.2	18.8	33.6	38.4	48.	60.	72.
60	5	12.	15.	18.	24.	30.	36.	42.	48.	60.	75.	90.
60	7.5	18.	22.5	27.	36.	45.	48.	63.	72.	90.	113.	135.
60	10	24.	30.	36.	48.	61.	72.	84.	96.	120.	150.	180.
60	12	28.8	36.1	43.3	57.7	73.	86.	101.	115.	144.	180.	216.
60	15	36.	45.	54.	72.	91.	108.	126.	144.	180.	225.	270.
60	20	48.	60.	72.	96.	122.	144.	168.	192.	240.	300.	360.
70	½	1.4	1.75	2.1	2.8	3.5	4.2	4.9	5.6	7.0	8.75	10.5
70	1	2.8	3.5	4.2	5.7	7.1	8.4	9.8	11.2	14.	17.5	21.
70	2	5.6	7.0	8.5	11.3	14.1	16.8	19.6	22.4	28.	35.	42.
70	3	8.4	10.5	12.7	17.0	21.2	25.2	29.4	33.6	42.	53.	63.
70	4	11.2	14.	17.0	22.6	28.3	33.4	39.2	44.8	56.	70.	84.
70	5	14.	17.5	21.	28.	35.	42.	49.	56.	70.	88.	105.
70	7.5	21.	26.3	31.5	42.	53.	63.	74.	84.	105.	132.	158.
70	10	28.	35.	42.	56.	70.	84.	98.	112.	140.	176.	210.
70	12	33.6	42.	50.5	67.	84.	101.	118.	134.	168.	211.	252.

70	15.	43.	53.	63.	84.	106.	126.	148.	168.	210.	264.	316.
70	20.	57.	71.	85.	113.	142.	168.	201.	226.	284.	355.	426.
80	½	1.6	2.0	2.4	3.2	4.0	4.8	5.6	6.4	8.0	10.	12.0
80	1.	3.3	4.05	4.8	6.5	8.1	9.6	11.3	13.0	16.2	20.25	24.3
80	2.	6.5	8.1	9.7	12.9	16.2	19.4	22.6	25.8	32.4	40.5	48.6
80	3.	9.6	12.1	14.5	19.4	24.2	29.	34.	38.8	48.4	60.5	72.6
80	4.	13.	16.2	19.4	25.9	32.3	38.8	45.3	51.8	64.6	80.8	97.
80	5.	16.1	20.2	24.2	32.3	40.4	48.4	56.6	63.6	80.8	101.	121.
80	7.5	24.1	30.3	36.3	48.4	60.6	72.6	84.9	94.4	121.	152.	182.
80	10.	32.2	40.4	48.4	64.6	80.8	96.8	113.2	127.2	161.6	202.	242.
80	12.	38.7	48.5	58.1	76.5	97.	116.	136.	153.	194.	243.	291.
80	15.	48.3	60.6	72.6	96.9	121.	145.	169.	191.	242.	303.	363.
80	20.	64.4	80.8	96.8	129.2	161.6	193.6	226.4	254.4	323.	404.	484.
100	½	2.0	2.55	3.05	4.1	5.1	6.1	7.15	8.2	10.2	12.8	15.3
100	1.	4.1	5.1	6.1	8.2	10.2	12.2	14.3	16.4	20.4	25.5	30.6
100	2.	8.2	10.2	12.2	16.4	20.4	24.4	28.6	32.8	40.8	51.	61.2
100	3.	12.3	15.3	18.3	24.6	30.6	36.6	42.9	49.2	61.2	76.5	91.8
100	4.	16.4	20.4	24.4	32.8	40.8	48.8	57.2	65.6	81.6	102.	122.4
100	5.	20.5	25.5	30.5	41.0	51.0	61.0	71.5	82.0	102.	127.5	153.
100	7.5	30.3	38.3	45.8	61.5	76.5	91.5	107.2	123.	153.	191.	230.
100	10.	41.	51.	61.	82.	102.	122.	143.	164.	204.	255.	306.
100	12.	49.2	61.2	73.2	98.4	122.4	146.4	171.6	196.8	244.8	306.	367.
100	15.	61.5	76.5	91.5	123.	153.	183.	214.5	246.	306.	383.	459.
100	20.	82.	102.	122.	164.	204.	244.	286.	328.	408.	510.	612.

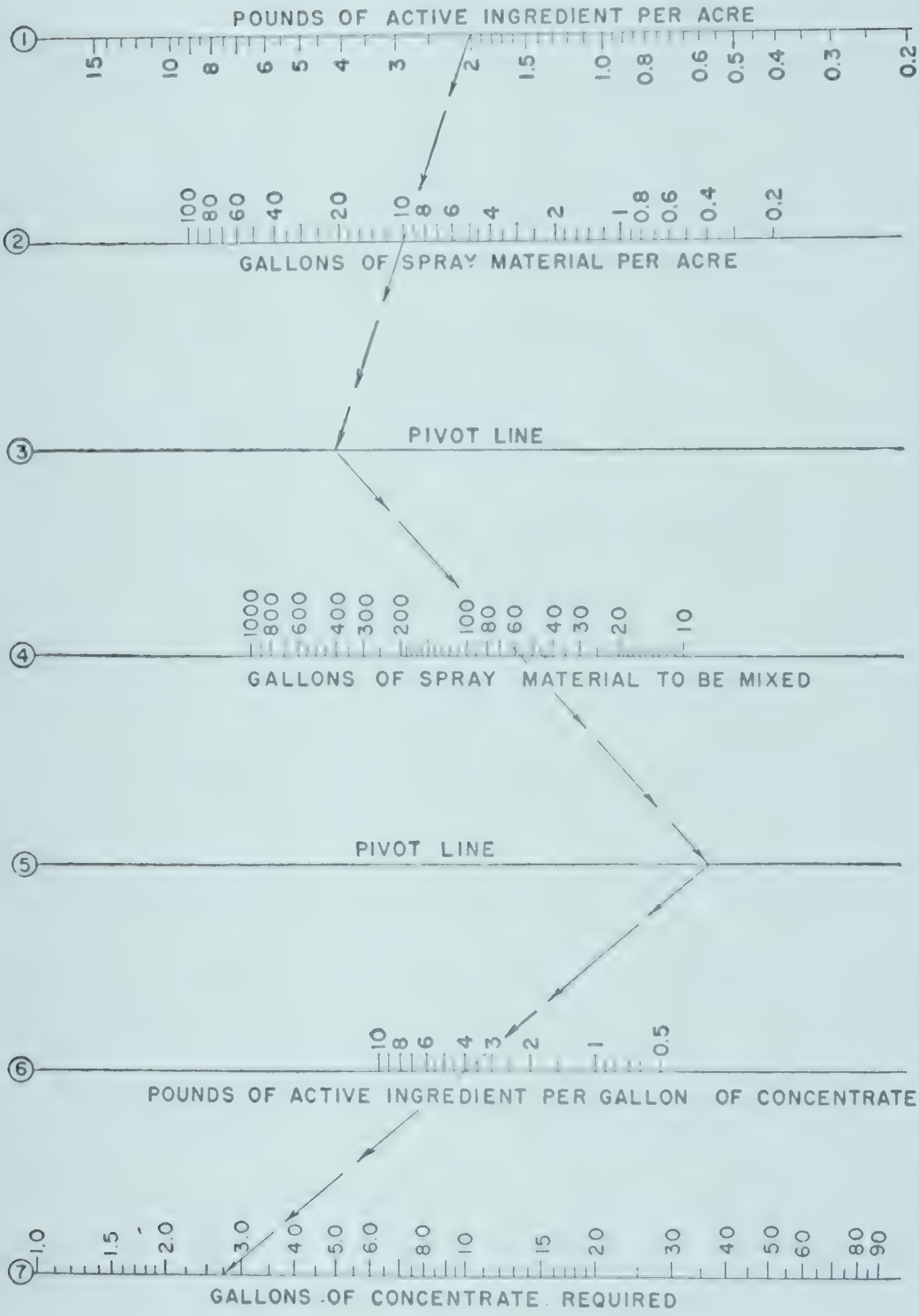

①
POUNDS OF ACTIVE INGREDIENT PER ACRE
15
10
8
6
5
4
3
2
1.5
1.0
0.8
0.6
0.5
0.4
0.3
0.2
②
100
80
60
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
GALLONS OF SPRAY MATERIAL PER ACRE
③
PIVOT LINE
④
1000
800
600
400
300
200
100
80
60
40
30
20
10
GALLONS OF SPRAY MATERIAL TO BE MIXED
⑤
PIVOT LINE
⑥
10
8
6
4
3
2
1
0.5
POUNDS OF ACTIVE INGREDIENT PER GALLON OF CONCENTRATE
⑦
1.0
1.5
2.0
3.0
4.0
5.0
6.0
8.0
10
15
20
30
40
50
60
80
90
GALLONS OF CONCENTRATE REQUIRED

Chart 1

the liquid remaining in the tank, and (4) compute the flow rate in gallons per minute. An alternate method is to (1) fill the tank to a definite level, such as a specific point in the filler neck, (2) fly the plane as described above, (3) after landing, spot the plane in exactly the same location used when filling the tank and measure the amount required to refill to exactly the same level, and (4) compute the flow rate as above. Two or three replicate flights should be made, and the results for any one spray mixture should not vary by more than 3 per cent. Fuel oil alone can be used for determining the flow rates of DDT-fuel oil solutions. For emulsions and suspensions the mixed sprays should be used. The flow rate required can be computed by the formula.

$$F = \frac{S\ W\ D}{495}$$

when F = flow rate (output) in gallon per minute
S = speed of the plane in miles per hour
W = width of effective swath (not total swath) in feet
D = dosage to be applied in gallons of liquid spray per acre

Any delivery rates in gallons per minute may also be computed as follows: $D = \frac{R\ S\ W,}{495}$

D = Delivery required, in gallons per minute
R = Application rate, in gallons per acre
S = Flight speed, in miles per hour
W = Swath width treated, in feet

The swath width of planes equipped with a full-wingspan-boom can be estimated roughly by multiplying the wingspan by 3.5 to 4. However, this is only an approximation. It applies only to planes in which spray is released over the full wingspan, and from a height above the trees greater than the wingspan."

Corrosion of Aircraft Structural Materials

SOME of the manufacturers of ground equipment are already using corrosion-resistant protectives, and it would be well for the aircraft operators to try some of the materials now being used by them.

At Texas A & M, Schreiber (1955) has tested various materials for aircraft. His findings may be summarized as follows:

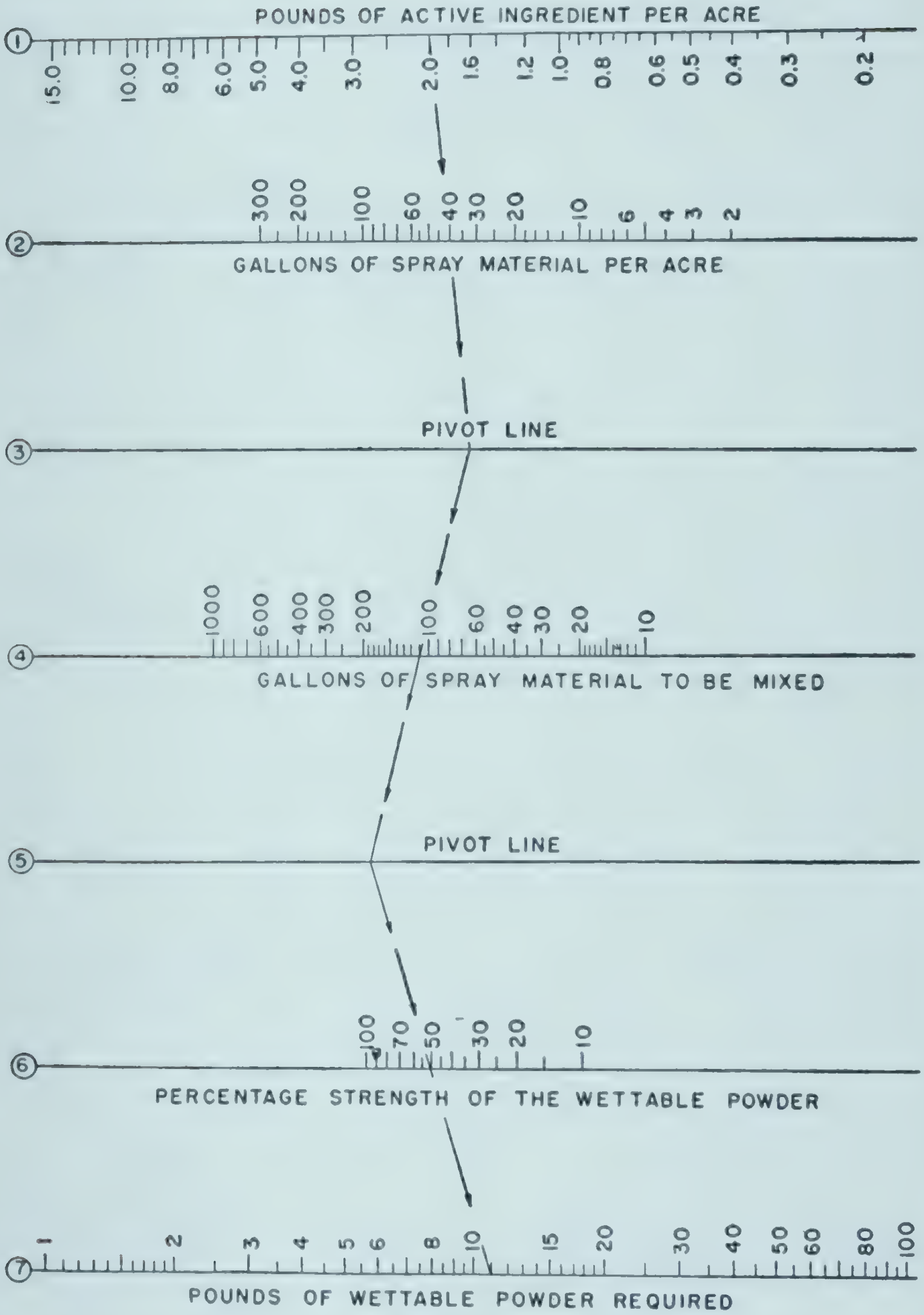

POUNDS OF ACTIVE INGREDIENT PER ACRE
①
15.0 10.0 8.0 6.0 5.0 4.0 3.0 2.0 1.6 1.2 1.0 0.8 0.6 0.5 0.4 0.3 0.2
②
300 200 100 60 40 30 20 10 6 4 3 2
GALLONS OF SPRAY MATERIAL PER ACRE
③
PIVOT LINE
④
1000 600 400 300 200 100 60 40 30 20 10
GALLONS OF SPRAY MATERIAL TO BE MIXED
⑤
PIVOT LINE
⑥
100 70 50 30 20 10
PERCENTAGE STRENGTH OF THE WETTABLE POWDER
⑦
1 2 3 4 5 6 8 10 15 20 30 40 50 60 80 100
POUNDS OF WETTABLE POWDER REQUIRED

Chart 2

None of the coatings provided a perfect corrosion-free finish against all of the agricultural chemicals. The furan finish with a butyral wash primer, however, demonstrated excellent resistance to the vast majority of chemicals tested. Wider recognition of this type of finish should be observed because its physical properties are suitable for aircraft. The furan finish as used was easily sprayed, brushed, or dipped, and no trouble was encountered during application.

Of the structural materials tested only two, type 302 stainless steel and polyester plastic reinforced with fiberglass, showed complete resistance to all of the solutions investigated. Either of these materials should be very satisfactory for tank or hopper construction, if weight requirements can be met.

Stainless steel appears to be the best material available for corrosion-free piping and plumbing systems. Monel, which is easier to machine, showed up reasonably well, however. Brass, aluminum, alloy and chrome-molybdenum steel were all destroyed by certain chemicals.

Since most of the tanks and hoppers already constructed are of an aluminum alloy, the possibility of using an inhibitor with such extreme corrosives as TCA should be investigated, using various percentages of sodium chromate and sodium dichromate in solution with TCA. Aluminum of all types should be tried. Also, the above inhibitor will possibly work with such compounds as sodium cyanamide.

The spraying units and all structural parts of the aircraft exposed to chemicals should be cleaned thoroughly immediately after use.

Charts for Calculating Mixtures

TO help solve mixing problems that arise when working with liquid-concentrate pesticides, use Chart No. 1.

Example

Suppose you want to apply 2 pounds of active ingredients per acre. The rate of application of spray material is 10 gallons per acre, the tank capacity is 55 gallons, and the concentrate has 4 pounds of active ingredient per gallon.

Using the chart, find 2 pounds per acre on Scale 1. Find 10 gallons per acre on Scale 2. Draw a straight line through these two points to Scale 3; from this point on Scale 3, draw a straight line through 55 gallons on Scale 4, and intersect Scale 5. From this point on Scale 5, draw a straight line through 4 pounds of active ingredient per gallon of concentrate on Scale 6, and read the gallons of concentrate to be used on Scale 7. The amount required is 2.75 gallons.

To solve mixing problems that arise when working with wettable-powder pesticides, use Chart No. 2.

Example

Suppose you want to apply 2 pounds of active ingredient per acre. The rate of application of spray material is 40 gallons per acre, 110 gallons of spray material are to be mixed, and the wettable powder is 50 per cent strength.

Find 2 pounds per acre on Scale 1. Find 40 gallons per acre on Scale 2. Draw a straight line through these two points to Scale 3; from this point on Scale 3, draw a straight line through 110 gallons on Scale 4, and intersect Scale 5. From this point, draw a straight line through 50 per cent wettable powder on Scale 6, and read the amount of powder needed—11 pounds—on Scale 7.

Spray Formulas

THE number of pounds of pesticide needed to mix a spray containing a given per cent of active ingredient can be calculated by using the following formula:

$$\frac{\text{Gallons of spray wanted x 8 x per cent of active ingredient wanted}}{\text{Per cent of active ingredient in pesticide used}}$$

$$= \text{Pounds of pesticide to be used.}$$

$$\text{Acres per minute} = \frac{2 \text{ s.w. x m. p. h.}}{1{,}000}$$

$$\text{Gallons per minute} = \frac{2 \text{ s.w. x m. p. h. x g. p. a.}}{1{,}000}$$

s.w., effective swath width in feet.

m. p. h., speed of airplane in miles per hour.

g. p. a., application rate in gallons per acre.

Example

How many pounds of 6 per cent gamma BHC wettable powder are needed to make 50 gallons of spray containing 0.03 per cent of gamma BHC?

$$\frac{50 \times 8 \times 0.03}{6} = 2 \text{ pounds}$$

The per cent of active ingredient in a spray mixture can be calculated by using the following formula:

$$\frac{\text{Pounds of pesticide used x per cent of active ingredient in pesticide}}{\text{Gallons of spray mixture x 8}}$$

$=$ Per cent of active ingredient in the spray.

Example

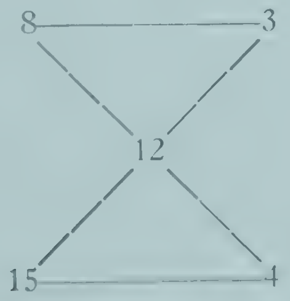
Two pounds of 6 per cent gamma BHC wettable powder is mixed with 50 gallons of water. What per cent of BHC is in the spray?

$$\frac{2 \times 6}{50 \times 8} = 0.03 \text{ per cent}$$

The formulas above work for emulsifiable concentrates, when measured in pounds, as well as for wettable powders.

To figure solution percentages, use the formula illustrated below.
Given: Two solutions of 8 per cent and 15 per cent.
Wanted: A solution of 12 per cent.

To find how much of each solution to use, subtract the smaller figure from the larger figure diagonally, as follows:



12 from 15 = 3

8 from 12 = 4

Now, by reading horizontally, you find that 3 parts of the 8 per cent solution mixed with 4 parts of the 15 per cent solution will give you a 12 per cent solution.

Literature Cited

Hedden, O. K. 1952. Aerial-spray equipment for a piper cub J-3 airplane. USDA, A.R.A., Bur. Plant Indus., Soils, and Agr. Eng., Info. Series No. 88, mimeo., illus.

Miller, C. W. 1935. Introduction to Physical Science, Ed. 2. J. Wiley & Son, New York and London.

Potts, S. F. 1940. Concentrated spray mixtures and their application by ground and aerial equipment as compared with standard spraying and dusting methods. U.S.D.A., Bur. Ent. and Plant Quar., E-508, 20 pp., illus.

———— 1946. Particle size of insecticides and its relation to application, distribution, and deposit. *Jour. Econ. Ent.* 39(6) : 716-720.

————, P. Garman, R. B. Friend, and R. A. Spencer. 1950. Construction of ground equipment for applying concentrated sprays. Conn. Agr. Expt. Sta., Cir. No. 178, 35 pp.

Schreiber, C. F. 1955. Corrosion of aircraft structural material by agricultural chemicals. Texas A. & M. College System, Reprint No. 38, 119-130.

Sell, W. 1931. Staubausscheidung an einfachen Korpern und in Luftfiltern. Forschungsarbeiten Verin deutschen Ingenieuren V.I.D., Verlag No. 347.

Wooten, O. B., W. R. Smith, and W. E. Meek. 1950. Cultivator spray rig for farm tractor. Miss. Agr. Expt. Sta., Bul. No. 472, 19 pp., illus.

Yeomans, A. H. and E. E. Rogers. 1953. Factors influencing deposit of spray droplets. *Jour. Econ. Ent.* 46(1) :57-60.

———— and van Leeuwen. 1954. Insecticide spray deposits. *Soap and Sanitary Chem. Mag.* 30(4) :141-144.

Yuill, J. S., Eaton, C. B., and Isler, D. A. 1951. Aircraft spraying for forest pest control. U.S.D.A. Bur. Ent. and Plant Quar., E-823, 21 pp.

CHAPTER III

GROUND SPRAY EQUIPMENT

INVESTIGATIONS of the fundamentals of concentrated spray application have resulted in the development and modification of a number of machines of various types and sizes as shown by Potts, Garman, Friend, and Spencer, 1950 (pp. 1-35). These include hand atomizers (Potts, 1940, pp. 3-4 and Potts, 1951, pp. 1-4), nozzles for knapsack sprayers (Potts, Cline, and McIntyre, 1942, pp. 406-409), a knapsack mist blower, a small 1 to 2 hp. wheelbarrow and skid model mist blower (Potts and Spencer, 1947, pp. 1-3), and various sizes of medium to large shade tree and orchard mist concentrate machines as described by Potts, Garman, Friend, and Spencer (1950) and Garman (1953). Also included are contributions to the development of so-called low gallonage nonblower-type equipment (Potts and Friend, 1946, pp. 48-50) using nozzles with small orifices, spaced on booms or row cultivators, for applying herbicides and insecticides to fields of small grain, pastures, and row crops. A machine of this type was developed and tested by Potts in 1940 on pastures and row crops to control white-fringed beetles and truck crop insects. During the past five years over 85 million acres have been treated with low gallonage rigs and at least 300,000 machines of various types have been built.

The popularity of these nonblower concentrate rigs has been due to their low cost, light weight, and simplicity. However, they have the following limitations: (a) they cannot treat trees and are restricted to low-growing vegetation, (b) the finest spray has droplets averaging 75 microns or greater in diameter compared with the optimum drop diameter of 40 to 50 microns as shown by Potts (1946), and (c) they cannot apply wettable powder suspensions through small orifice nozzles without too much clogging.

When the size of the nozzle orifices is increased to $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter to apply suspensions, the spray is too coarse (200 to 400 microns drop diameter) and the gallonage delivered per acre is too great for maximum economy. According to Wilson (1952), information so far obtained does not justify the use of concentrates greater than 5x concentration (30 gallons per acre) when applying the coarse spray with nonblower equipment for vegetable disease control.

Nevertheless, the nonblower "low gallonage" concentrate rigs may continue to outrank mist blowers in total crop acreage treated where complete coverage is not required, because of their features of low cost, light weight, simplicity, and the impetus of strong initial acceptance.

Hand atomizers and knapsack sprayers have a far greater field of use than is generally recognized by potential users.

Pumps

AN essential part of nearly all power sprayers is a liquid pump. There is no pump that is best for all sprayers and conditions. The best pump for a particular sprayer is one that delivers the desired spray volume at the required pressure for an economical span of service. A pump must also be suited for the particular type of drive to be employed, whether a direct drive on the engine shaft, power take-off, or V-belt. The widespread use of concentrated sprays accentuates the wear problem and makes the correct selection of a pump more critical.

Gunkel (1954) has conducted a series of laboratory tests on 17 low-volume sprayer pumps. In addition, 12 Hypro Model 750 Roller Vane Pumps with Ni-Resist cases and Nylon Rollers were field-tested. The spray mixture used contained 24 pounds of hydrated lime and 48 pounds of wettable sulfur per 100 gallons of water. He concludes in part: ". . . Both the Ace Single and Double Diaphragm types of pumps were superior to the others tested. After 500 and 700 hours, respectively, of pumping, the diaphragm pumps were still in excellent condition. The cast-iron semi-open impeller centrifugal type of pump also has definite merit. Unfortunately, it is severely limited in its discharge pressures. As pressures vary with r.p.m., the speed of rotation is a limiting factor."

There are three general kinds of pumps which may be used; plunger, centrifugal, gear, and diaphragm. Plunger and diaphragm pumps can deliver any kind of mixture at any pressure. They are heavier and more durable than gear types. Metal centrifugal pumps can deliver any kind of mixture at low pressures (below 40 p.s.i.).

Spur type gear pumps can deliver up to 150 pounds pressure at 1,200 to 2,000 r.p.m. Ordinarily, abrasives like sulfur and cryolite will wear off the gears at such high speeds and pressures that present types of gear pumps do not last long when applying such abrasive substances at high speeds with pressures above 15 to 20 pounds. However, at pressures of 2 to 15 pounds and at speeds of 350 to 700 r.p.m., good ones may last one to three years. They are usually more satisfactory than centrifugal pumps for most mist blowers. For the small machines a ¼″ gear pump is adequate; however, large rigs may require a ⅜″ or ¾″ gear, or a 2- to 4-gallon-per-minute plunger pump.

The pumping systems require oiling, suitable liquid by-pass arrangements, relief valves, and pressure gauges with diaphragms to keep the liquid from entering the gauges. Gear pumps without "built-in" pressure relief regulators are preferable for general use. To pump at specified low pressures, a suitable relief valve and large capacity by-pass are essential. Steady pressure without pulsations is essential in all spray systems. Durable, non-leaking shaft and housing seals are essential.

In gear pumps the chrome plated gears last a little longer than straight brass gears. For high pressures and abrasive materials plunger pumps or diaphragm pumps will be needed. Plunger pumps turn at 60 to 180 rpm and require reduction gears or reduction pulleys for reducing to that speed. The large pumps turn slower than small ones. Many power take-off fits call for 1⅛ inch and 1⅜ inch splines, but special couplings can be obtained for 1¾ inch splines. The pumps should not be run if the tank is empty.

Seal breakdown is a common fault of sprayer pumps, and bearing failures are also frequent. A material known as "Teflon" has shown much promise as a seal for rotary pumps.

Pumps for Nonblower Weed and Cotton Sprayers

FROM the start, rotary pumps of one form or another have been used because of their small size and comparatively low cost. At the same time, however, they have been the greatest single weakness of the cotton sprayer. Bronze has been widely used because it does not rust. However, bronze pumps have proven erratic, some giving good service and others of the same make wearing out after short service. Iron gear pumps wear better and will last longer if the user will flush them out with oil after each usage with water. Nylon roller pumps have given good service but are higher in price. They are not as durable for dispersing wettable powder suspensions as are the plunger or diaphragm types.

PUMP LIMITATIONS NOTED. The subject of pumps for low gallonage sprayers is one badly in need of additional research by industry. Several manufacturers have brought out models of tractor power take-off operated piston and diaphragm pumps, but none so far quite fills the bill. The ones made thus far are regarded as being too large and cumbersome, requiring a large compression chamber. They are also priced too high to attract the mass market. They are, however, a beginning. The final answer may be a simple lightweight, low-priced piston or diaphragm pump that operates directly from the tractor power take-off.

Washers, Gaskets, Hose

ALL washers, gaskets, and hose must be resistant to oil solvents. Disintegrating rubber parts in the line can plague the operator continuously by repeatedly plugging the nozzles. Leather washers and neoprene hose (such as Weatherhead hose) and some plastics are more resistant than natural rubber products. It is expected that some of the new plastic materials may replace rubber materials.

Hose lines have been a weakness of the cotton and weed sprayers. The best grades of synthetic rubber do not last long when not taken care of properly. Most users, unfortunately, will not bother to flush the spray out of the hoses after use. Prolonged contact with the common insecticide mixtures softens the hose and eventually causes it to go to pieces. The use of p-chlorophenyl in diesel fuel has been shown to be especially hard on rubber hose.

Several of the common plastics are highly resistant to insecticide mixtures. However, a plastic hose reinforced with fabric to stand high pressure is not yet available. One manufacturer of hose has indicated that they can and will make such a hose soon. Most plastic garden hoses are too soft to be used as an intake, being apt to flatten out due to the suction of the pump. Plastic garden hose is satisfactory for the overflow hose, but most types of hose of this kind will not stand sufficient pressure. This is especially true when the hose and contents have been heated by standing in the hot sun. One brand of heavy wall, tough plastic industrial hose is available that will withstand the pressure used for most cotton spraying and can be used successfully. The catch is, this type is not available in sizes under one-half inch.

The answer here could be a plastic hose of the several required sizes, made with a fabric embedded in it. Before long, such hose should be available, and then the grower can expect many years of service from his sprayer hose, even with the usual poor care.

Mist Blowers

THE mist blower is the most interesting of the spray machines because it embodies the principles of all types of ground equipment, and many of the principles of aircraft as well; it has a wider variety of uses and adaptations than other types. Mist blowers, however, have not had the volume of use enjoyed by the non-blower type low gallonage rigs, for only a small section of potential users are familiar with them.

The specific requirements and attachments for blower type applicators vary considerably with the kind of growth and size of areas to be treated. Table 41 indicates nine approximate sizes and capacities for general uses.

Fans and Outlets

IN mist blowers, the fan is the "heart" of the machine just as the pump is the "heart" of the hydraulic sprayer. Two methods of application characterize the use of fans as follows: (1) a high velocity of air at 185 to 300 mph. to atomize and project the spray, and (2) the use of a combination of medium high air velocity of 90 to 185 mph and hydraulic pressure nozzles or centrifugal spinner nozzles to break up the spray and distribute it.

Fan and outlet construction and requirements have been aptly discussed by Potts, Garman, Friend, and Spencer (1950) as follows: "There are two general types of fans, the axial flow and the centrifugal. So-called curved blade, squirrel cage or multivane, Soroceo, and multiple stage fans are merely modifications of these two types. No specific type of fan is best for all conditions, for a given fan may influence the design of a machine favorably for some jobs and unfavorably for others.

"Belt drives, and some direct drives, have been successful. Weakly constructed right angle gear drives always break down. However, a strong, specially constructed right angle drive can be made to work on a strong, steady frame. Fans should be steady and as free of noise as possible.

Table 41. Horse power, weight, and air capacity of mist blowers.

Horse power requirement	Weight pounds	Air velocity m.p.h.	Air volume cu. ft. per min.	Preferred mounting
1.5 to 2	90-100	225	150	Wheelbarrow, pickup truck trailer, small tractor
4 to 5	300	180	800	Trailer, truck, tractor
7	500 and 200*	175	1,700	Trailer, truck, big tractor
12	600 and 300	145	3,600	Trailer, truck, tractor
15	700	145	4,000	Trailer, truck, big tractor
25 to 30	1,800 to 2,000	135	8,000	Truck, tractor-drawn trailer
40 to 50	3,000	125	12,000 to 15,000	Truck, tractor-drawn trailer
25	2,000	80 to 100	19,000	Truck, tractor-drawn trailer
75**	4,000 to 5,000	120	24,000 to 30,000	Tractor-drawn trailer

* Weight of 200-300 pounds refers to use with light two-cycle engine.
** For discharging from both sides of machines.

"The principal factors determining the type of fan to use are the air velocity required to break up and deposit the spray, the size of the machine, and whether the outfit is to be operated by one man or two men. In general, very small rigs utilize high velocity air to break up the spray by shearing action. Hence, they may use high velocity, low volume, single or double stage fans. Usually the medium to medium large rigs employ a combination of air velocity of 125 to 150 m.p.h. and hydraulic pressure of 150 p.s.i.* or less, through whirl nozzles to atomize the spray. Machines of this type usually have delivered about 4,000 to 10,000 c.f.m.** of air by either of the two types of fans. Most very large orchard machines deliver 14,000 to 36,000 c.f.m. Machines of very high volume and low velocity may require a small, high velocity, low volume auxiliary blower to break up the spray and distribute it into the air stream from a big fan, or they may atomize the spray with whirl or fan type nozzles at 200 to 600 p.s.i. For most shade tree work, air velocities of 120 to 150 m.p.h. are required in volumes of at least 8,000 c.f.m. Volumes of 12,000 to 15,000 c.f.m. at velocities of 120 to 135 m.p.h. are preferred, or 18,000 to 26,000 c.f.m. of air at 95 to 115 m.p.h. for 70- to 120-foot trees, especially where elm bark beetles and certain other pests in the tops of the trees are to be controlled.

"There is an optimum ratio between velocity and volume at the orifice to attain the greatest height and distance with a given horse power under operating field conditions. The volume of air delivered is directly proportional to the square of the diameter of the outlet. Thus, a 24-inch outlet delivers four times as much air as one 12 inches in diameter at the same velocity. In shade tree work, the optimum velocities for various sized outlets are given in Table 42. The figures in Table 42 do not correspond exactly to those of Table 41, due primarily to a slight difference in outlet size, nor do the figures correspond with those of Table 43, since Table 43 represents the actual machine in use while Table 42 represents the optimum conditions."

"In small machines like the wheelbarrow model, a much higher air velocity (200 to 300 m.p.h.) has been employed because air velocity provides the means of atomizing the spray.

"The spray delivery for the different sized air outlets will vary as follows:

---

* Pounds per square inch.

** Cubic feet per minute.

Outlet diameter inches	Spray delivery (gallons per hour)	
	Range	Efficient for most purposes
1.25	5 to 15	7
2	10 to 25	14
4	15 to 40	20
10	20 to 72	40
12	25 to 120	50
15	30 to 150	60
18	35 to 168	70
20	40 to 180	80
24	45 to 180	90

In the large machines spray delivery should be calibrated to permit regulation of any specified delivery between 20 and 180 gallons per hour (⅓ to 3 gallons per minute).

"The size, shape, and flexibility of the outlet are important. For the small machines that deliver high velocities a very flexible outlet is essential to obtain even coverage. The round, straight, short outlet is the most efficient shape for shade tree and mosquito work where the fine spray must be driven to great distances. For the large, one man-operated orchard machines some air and power efficiency must be sacrificed in order to effect sufficient spread close to the machine, as shown in Table 43. This spread may be obtained with slot or fish-

Table 42. Optimum velocity and volume for round outlets of given diameter for tree application.*

Diameter of outlet inches	Optimum velocity m.p.h.	Volume c.f.m.
4	170	1,300
8	150	4,200
10	145	6,300
10.5	140	6,300
12	130	8,000
15	126	**
18	123	**
20	120	21,000
24	115	27,000 (approx.)

From Potts, Garman, Friend and Spencer, 1950, p. 8.
* This is ORIFICE velocity. Deposition velocity is much less.
** Figures not available.

Table 43. Air velocities at given horizontal distances from blowers, delivery through round outlets of given diameter.*

Diameter of outlet inches	Approximate volume c.f.m.	Velocity (m.p.h.) at the following distances (in feet) from blower							
		At blower outlet	10	25	50	75	100	150	200
1	140	300	15	2	0				
1.25	200	225	20	3	0				
2	370	200	30	5	1	0			
4	1,300	170	40	8	2	0.2	0		
8	3,800	125	40	10	3	1	0		
10	6,100	140	70	35	6	3	1.8	0	
10.5	6,300	140	75	40	7	3	2	0 to 1	
12	7,500	125	60	30	7	4	2.5	1	0
24	20,000	90	50	25	7	6	4	2	0
24	28,000	120	75	40	17	10	9	7	3
54**	27,000	50	35	30	8	4	3	2	0

From Potts, Garman, Friend, and Spencer, 1950.

* Air gauges used were. (1) a gauge for measuring air velocity in terms of inches of water pressure, (2) an airplane pressure gauge, (3) low velocity gauge, and (4) an anemometer.

** Not an enclosure outlet.

tail outlets with spreader vanes or spoilers, or with multiple round ones."

"Air speed at given distances from a fan depends on eight factors as follows: (1) air velocity, (2) air volume, (3) diameter of round outlet, width of fish tail, or slot outlets, (4) shape of outlet and angle of spreader deflectors, (5) the temperature and the air's moisture content and weight, (6) upward or downward air currents, (7) wind velocity and direction in relation to direction of discharge from blower, and (8) rate of travel of machine. Travel reduces distance and air speed. Two m.p.h. travel is equivalent to a five mile wind.

"The relative distances to which air is driven from slot type outlets that compare to round outlets is indicated by the data in Table 44.

"The flexibility of the outlet may determine the type of fan to use for highest operational efficiency. For example, certain axial flow fans are more efficient in moving air straight away from the fan than the paddle or centrifugal type fans. However, to use axial flow fans in shade tree work, it is necessary to expend some horse power in forcing a directional change in the air stream, or to place the fan in the back end of a straight air discharge pipe so that it can automatically rotate with the outlet without changing air flow direction. On the other hand, some of the paddle or centrifugal fan cases with straight short outlets can be rotated or easily swung up and down in a 180° to 230° arc with no loss of air efficiency. This feature covers about 90 percent of the situations in general operation, and a 180 degree (half turn) turntable is sufficient to take care of the others. This provision also permits making the rig shorter, more flexible, simpler, and more efficient in operation.

"The large machines, at least, should be designed for changing the shape and width of the air stream quickly while the machine is moving. Moreover, it is now possible to change the velocity of the air stream without changing the drop size, and to apply a wide, 'soft' air-spray stream close to the machine and suddenly change to a narrower, higher velocity stream to attain greater height and distance. This is accomplished by utilizing a fan of high velocity (as 175 to 225 m.p.h.) and low volume (as 150 to 300 c.f.m.) to atomize the spray into the air stream from another fan of large volume (as 15,000 to 40,000 c.f.m.) and low velocity (as 50 to 100 m.p.h.). Except in the case of relatively coarse sprays, the air velocity of the latter fan is not sufficient to greatly change the drop size. For spraying close to the machine the air stream can be spread by deflectors or spoilers located at the mouth of the outlet.

Round Air Outlets and Nozzles for Tall Trees

"A VERY useful 12-inch diameter nozzle manifold for air velocities of 120 to 150 m.p.h., is shown in Figure 25. With this assembly, which includes a set of short and long nipples, plugs, and reducer couplings, from one to four nozzles of ¼-inch or ⅛-inch connection can be attached. For most work, two to four nozzles are placed at the mouth of the outlet in the air blast, usually at right angles to it. This fills the air stream with spray. Another 12-inch outlet is made for three nozzles instead of four. Two or three makes of nozzles have been satisfactory, including the Whirljet types B1, B2, B3, and B5.

"With this manifold, it is possible to place the nozzles at any point between the center of the outlet and a position outside the

Table 44. Dimensions of slot type outlets and round outlets required to drive air same distance* at given velocity.

Dimensions of Slot Outlet inches	Square area of slot outlet (sq. in.)	Diameter of round outlet inches	Area of round outlet sq. in.
3 x 24	72	5.1	20.5
3 x 36	108	5.4	23.0
3 x 50	150	5.7	25.5
3 x 70	210	6.0	28.3
3 x 96	288	6.4	32.2
3 x 100	300	6.4	32.2
4 x 20	80	6.3	31.2
4 x 30	120	6.6	34.1
4 x 36	144	6.7	35.1
5 x 40	200	8.1	51.3
6 x 30	180	9.2	66.5
6 x 60	360	9.7	73.5
6 x 70	420	9.9	78.0
7 x 70	490	11.2	98.0
7⅓ x 70	513	11.6	105.7

From Potts, Garman, Friend, and Spencer, 1950, p. 10.

* Formula: To determine the diameter of round outlet required to give the same distance as a slot outlet of given dimensions:

$$W \times 1.8 + \frac{\sqrt{L}}{4} = D,$$ where

W = width of slot, and
L = length of slot
D = diameter of round outlet

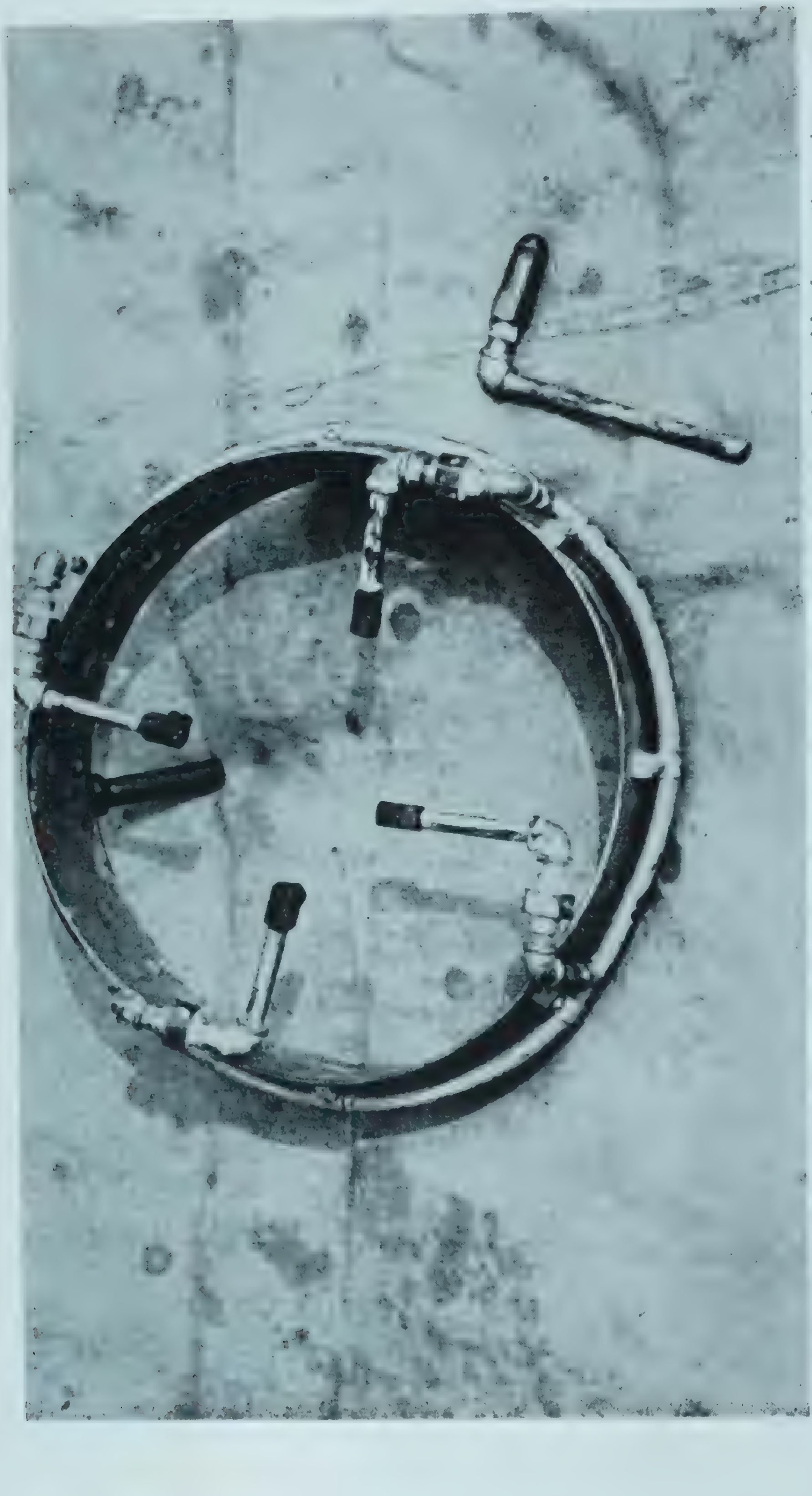


Figure 25. Nozzle manifold and assembly for 12-inch diameter round air outlet. Adjustable for setting given numbers of direct pressure nozzles of various sizes and types at given positions inside or outside of the outlet. Nozzles may be turned at any angle in relation to direction of air blast.

Potts, Garman, Friend, and Spencer, 1950.

outlet. Moreover, the nozzles can be pointed at any angle, so as to spray in any direction in relation to the direction of the air blast. In all our work with round outlets, however, we have found it best to place the nozzles inside the air blast.

"When spraying the tops of tall shade trees with a medium coarse spray, a B5 or B10 whirljet nozzle is used in the center of the outlet on the nipple shown at the right of the outlet in Figure 20 in Chapter II.

"For 18 to 25 inch diameter outlets delivering air at 85 to 110 m.p.h. a single B3 or B5 nozzle may be placed in the center of the outlet, and a pressure of 100 to 300 p.s.i. applied to the liquid. Drop size can be increased by increasing the orifice size and decreasing the pressure.

Nozzles

"NOZZLES must be capable of delivering any kind of mixture at appropriate rates. It should be possible to regulate the mass average drop diameter from 28 to 85 microns. This is ordinarily equivalent to a numerical average diameter of approximately 23 to 75 microns.

"Large droplets carried in air at low velocities are deposited more readily than small droplets. Since air velocity from mist blowers reduces rapidly as distance from the blowers increases, it is advantageous to apply droplets of 41 to 65 microns for coverage at distances greater than 50 feet from the machine. A greater proportion of small droplets will deposit per unit area on small objects, such as insect antennae and pine needles, than on large objects such as oak leaves, because of the greater air 'cushion' and eddies around the large objects. According to Yeomans and Rogers (1950) the minimum air velocity for efficient deposition with elevation or distance is 2.2 m.p.h. for 50-micron droplets when the sprayed objects are ¼-inch in diameter and 16.2 m.p.h. when the objects are two inches in diameter. For 100-micron droplets the optimum air velocity was calculated to be 1.1 m.p.h. for ¼-inch wide objects, and 4.6 m.p.h. for 2-inch wide objects. Rate of fall and drift are other factors concerned in degree of atomization. For example, in still air, droplets of 200, 100, 50, and 20 microns in diameter will fall 50 feet in 13, 51, 204, and 1,260 seconds, respectively. Droplets 200, 100, 50 and 25 microns in diameter will drift 43, 175, 700 and 2,800 feet, respectively, while falling 50 feet in a two m.p.h. wind.

"Clogging must be avoided or reduced to a minimum. Clean tanks and suitable strainers in the line immediately back of the nozzles, the absence of whirl grooves in the nozzles and the use of nozzle orifices of at least 1/16 inch in diameter when applying abrasive suspensions and viscous oils and emulsions help prevent clogging. At pressures greater than 30 pounds, hardened, steel nozzles are used to reduce erosion when applying concentrates containing abrasives like sulfur and wettable DDT. At pressures greater than 30 pounds, hardened, rustproof nozzles should be employed regardless of the mixture dispersed. The whirljet type nozzles with 1/8-inch female pipe connection have been fairly satisfactory at pressures of 30 to 100 p.s.i. The direct pressure nozzles must be placed inside the air blast to obtain maximum atomization by the air, and should be spaced in such a way that the mist is distributed throughout the air stream with as few nozzles as possible. This permits using larger orifices. Oil burner nozzles with fine screens and small (.01 to .03 inch) orifices are satisfactory for applying thin, light oils and emulsions, but will clog with suspensions. Heavy oils can be applied in emulsions containing up to 30 per cent oil.

"The optimum number of direct pressure nozzles on air-liquid nozzle manifolds varies with the diameter and number of air outlets and the nozzle output (g.p.m.*). For single air outlets less than seven inches in diameter, a single nozzle is usually pointed against the air blast or at right angles to it. In the case of multiple small outlets, one direct pressure nozzle per outlet may be installed, whereas, for a single 12-inch diameter outlet, the use of 3 to 4 nozzles at right angles to the air blast is satisfactory.

"For applying some of the heavy, viscous suspensions and straight, heavy oils at low temperatures, a pressure of at least 40 pounds is used and a nozzle with 3/32- or 1/8-inch orifice is pointed against the air blast and placed in the center of the outlet. Placing the nozzles in the same direction as the air stream results in too coarse atomization if pressure and air velocity are too low. At pressures varying from 12 to 700 p.s.i., the speed of water ejected from the orifices ranges from 28 to 220 m.p.h.** The atomization depends upon the difference in speed of the liquid versus the air velocity. Hence a stream from the nozzle directly against the air blast increases the shearing effect as the speed of the drop is added to the speed of air.

---

* Gallons per minute.

** $V = 8.3 \sqrt{\text{gauge pressure at nozzle}}$.

"The hollow jet (hollow tube) or shear type nozzle requires higher air velocity for atomization than direct pressure cone or fan nozzles, and a low liquid pressure of approximately 3 to 6 p.s.i. Larger air volumes also aid in atomization. For air outlets 1, 2, 4, and 12 inches or greater in diameter, air velocities of 250, 225, 180, and 150 miles per hour, respectively, are needed for fine atomization with these air velocity shear type nozzles. Particle size can be changed by changing the direction of the jets in relation to the direction of the air blast. Two sizes of hollow tube orifices ($\frac{1}{16}''$ and $\frac{3}{32}''$) are usually used. They are sharpened at their free ends to increase shearing action. For outlets 1, 1.5, 2, 4, and 12 inches in diameter, approximately 3, 4, 5, 6, and 8 tubes, respectively, should be used. The number of hollow jets can be reduced somewhat as the size of their orifice is increased. Provision can be made to reduce output by shutting off any number of tubes of the nozzle manifold.

"On large machines, an auxiliary high velocity blower to atomize the spray into the stream of high volume, low velocity air coming from a large fan offers possibilities of improvement. This arrangement permits a greater control of particle size range, since in our experience the low velocity air (30 to 80 m.p.h.) will not change materially the size of droplets smaller than 80 microns in diameter unless they are injected against the air blast. Moreover, this system generally permits a conservation of horse power, since it requires about twice the horse power to double the velocity at a given air output. The system has a disadvantage in that it adds another item, the small, auxiliary high velocity blower."

Tanks and Agitators

SUPPLY tanks should be of the correct size and shape. This depends on the capacity of the machine and the nature of application. On big machines 40- to 75-gallon tanks are suitable for shade tree spraying, but 75- to 300-gallon tanks are desirable for fruit trees. A round or trough-shaped bottom with a mechanical agitator is desirable for mixing any kind of material, and for agitation. By-pass agitation is insufficient. Paddle type agitators should move slowly, sweep the bottom, and be provided with a disengaging mechanism. Spiral blade agitators may move faster. For filling purposes, tanks should have a wide mouth provided with 12- to 16-mesh removable strainer. It is helpful to have a quantity gauge for reading the volume of mixture in the tank. The tank metal should be non-corrosive, and any paints applied to it should be able to withstand oil solvents and ordinary spray chemicals.

The construction must enable the operator to drain the tank and spray line quickly and completely. Hence, a large tank drain plug should be located conveniently. Sometimes it is handy to be able to connect a hose to the drain plug connection to convey the waste solution to a disposal spot. It is important to avoid strainer wells in the tank's bottom. It is also important to be able to shut off the tank from the spray line at a point immediately below the tank to prevent spray material from settling down into the spray line, strainers and nozzles.

The installation of an auxiliary 1 to 3 gallon graduated flush tank is helpful. This facilitates quick flushing of the spray line at the end of each spraying job or when changing mixtures. This small tank can be used as a material tank for small jobs or when treating individual trees. It should be connected to the main supply tank and provided with a shut-off between it and the supply tank.

There should be as few corners, turns, and restrictions as possible in the spray line between tank and nozzles. The pipe or hose line should be as short as practicable and of sufficient size (usually ¼ to ¾ inch inside diameter) to maintain a rapid flow and thus prevent stoppage by sludge.*

Other Construction Details

SCREW type valves should not be installed except for regulating pressure or liquid to be bypassed. A quick acting shut-off valve operated by a foot or hand lever is absolutely essential. It must be conveniently located so that the operator can use both hands simultaneously for "finger touch" manipulation of outlet and liquid and dust shut-off levers. It should also permit him to observe the spray operation continually without changing his line of vision.

One large-surface area strainer of approximately 16-mesh should be located between tank and pump. A 20-mesh strainer of smaller size should be placed in the line between pump and nozzles. All coarse mixtures prepared outside the machine should be poured through a strainer in the top of the spray tank. Spray materials of small particle size, need to be strained only to remove possible foreign matter.

Some means of measuring and regulating the quantity of spray material delivered per minute, per tree, per given area, or per given distance of travel is helpful. Hence, there is a definite need for at least one of three types of meters: a flow meter, a time (dial) meter, or a distance or low speed speedometer to measure rates of travel between 0 and 6 m.p.h.

---

* See Groves, Johnson and Walker. Washington Agr. Expt. Sta. Bul. 515. 1950.

The turntable may be power driven by hydraulic motor or electric motor equipment with generator; or the machine may be turned by the operator pushing the unit around with his feet while in the seat of the machine, or with a wheel and cable. The latter is the cheapest and simplest method. The turntable should be provided with a good hand or foot brake.

For shade tree and mosquito spraying, the machine is usually mounted on a truck with wide tires to reduce damage to lawns. For treating orchards, it is usually drawn on a trailer. For night work a good spot light can be mounted on the rotating outlet head or heads.

A throat microphone, or preferably a two-way chest microphone is useful for communication between operator and driver. The throat microphone costs less than 10 dollars, and consists of ear phones, four, 1½ volt dry batteries, a rubber covered, two-strand wire, and throat microphone.

Mechanically Produced Aerosol from Mist Blowers

A MECHANICALLY produced aerosol of 5 to 20 microns diameter droplets has been applied by delivering 10 to 30 gallons per hour of liquid through compressed air nozzles at 5 p.s.i. liquid pressure; and compressed air at 35 to 50 p.s.i. The compressed air nozzle was placed at the mouth of the outlet, or at right angles to the air blast of the blower. This system required the installation of a compressor. An aerosol of 10 to 25 microns average diameter can be produced by placing cone type oil burner nozzle tips at right angles to an air blast of 175 to 225 m.p.h. while applying a liquid pressure of 100 to 300 p.s.i. At 50 p.s.i. the nozzles should deliver 10 gallons per hour or less, per orifice (Figure 26).

Training Operators for Tree Spraying and General Applications

A GREAT deal could be accomplished by conducting mist blower schools and comprehensive short courses in tree spraying in connection with the Arborists' short course that is given each year at several colleges in the Northeast, Midwest, and Pacific Coast.

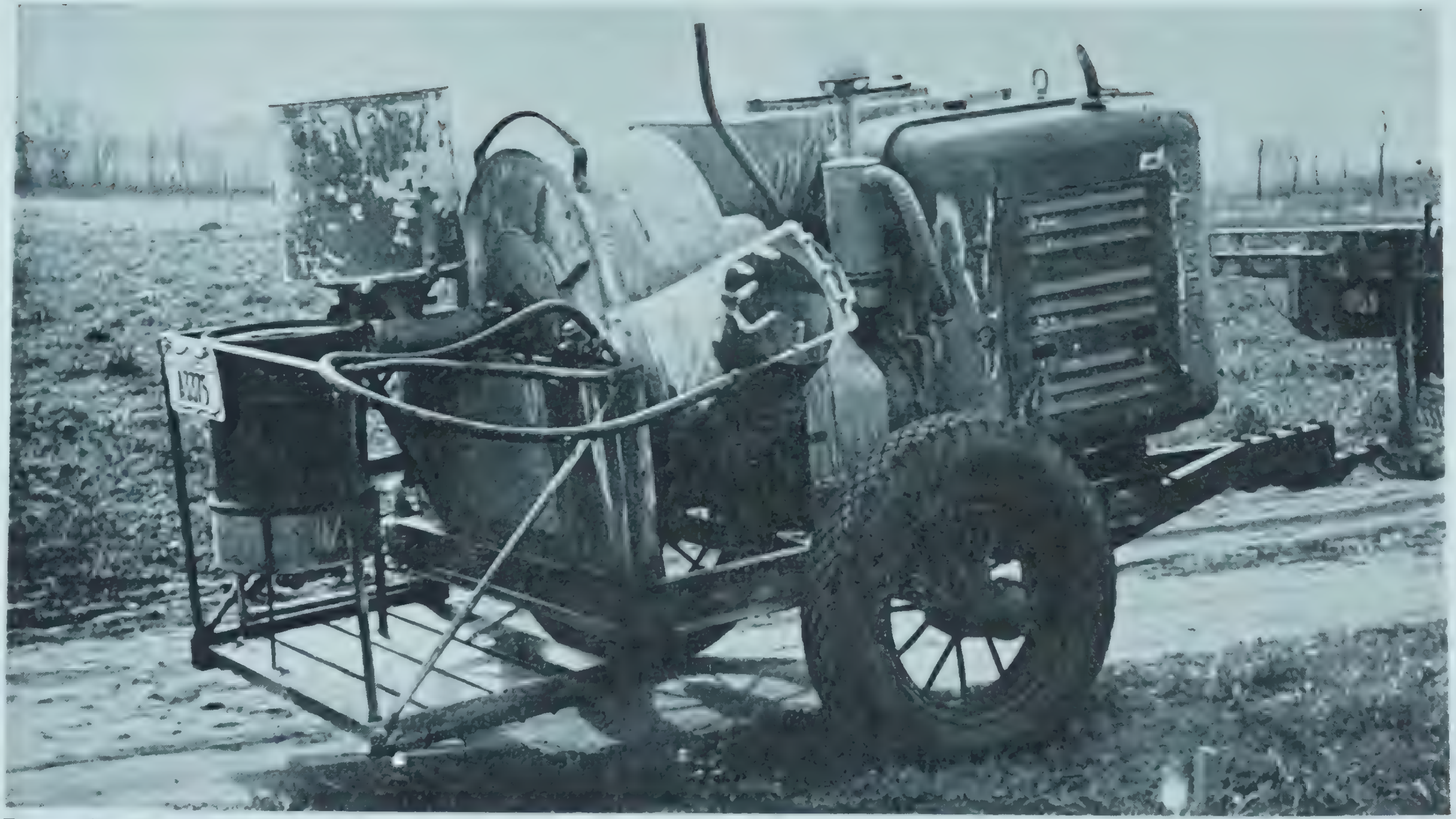


Figure 26. Twenty-five horsepower blower-atomizer on trailer showing large and small tank, dust hopper, hand-operated spray shutoff lever, and ring of eight oil-burner nozzles mounted in discharge outlet at a 45 degree angle to air blast.

Potts, Garman, Friend, and Spencer, 1950.

Crew training should be conducted prior to the start of the spray program. After competent men have been selected, they should be instructed carefully as to the mechanics of the machines, including their maintenance and repair, and how to operate them to obtain maximum coverage with a minimum of time and materials.

The training program should include: (1) instruction on how to apply a given volume of mixture to dormant and to foliated trees of given size and height; (2) how to regulate spray delivery; (3) how to treat a swath of given width at a given rate of travel with a given gallonage per acre; and (4) how to treat street and park trees, nurseries, woodlands, plantations, roadsides, city blocks, and marshes. Operators need to recognize the difference between treating for large, active chewing insects and mosquitoes as compared with treating for elm bark beetles, mites, scale insects and plant diseases which require a more complete coverage. Although theoretical and visual instruction is essential, the operators must learn by actually preparing the mixtures, making the treatments, and checking on performance.

Each crew needs an operations manual and information on the different formulations that will be needed for the various pests that may be encountered, including details on how to procure and mix the ingredients, when to make the application, and what volume to apply under various circumstances. It would often help, too, if manufacturers would designate what concentration and quantity of their product to use for various pests. Some progress is now being made in this regard.

Bid Specifications for Large Mist Blowers

THE best way to purchase a mist blower is to have a thorough knowledge of the available machines and what they are expected to do. Then the machine which is best suited can be procured by direct negotiation.

Unfortunately, municipalities, states, federal agencies and various other organizations usually have to purchase by issuing invitations to bid. The person who writes the bids should understand the various machines as well as the jobs they are expected to perform. Otherwise, the company that quotes the lowest price and makes the most extravagant claims will always be awarded the bid contract. The cheapest machine can of course be the best one, but usually it falls short of the best. If machine "A" costs twice as much as "B," it may be cheaper in the long run if it lasts longer, is easier to operate, causes less breakdown and delays, is cheaper to repair and maintain, and covers area more effectively and more rapidly. *Performance* is more important than *price*. Sometimes the list price of one machine appears to be much lower than that for another. But, actually, the purchaser may end up by paying more after having to procure needed carriage vehicles and attachments such as metering valves, speedometers, auxiliary tanks, special mounting facilities, automatic controls, etc. Often the most expensive machine is more durable, more adaptable, easier to operate and more efficient. However, this is not always true.

It might be wise to call attention to a few ways in which the uninformed purchaser can be misled. Statements regarding air velocity and air volume are starting points for many incorrect interpretations. For example, one manufacturer stated that his fan would deliver 14,000 c.f.m. of air and 175 to 200 m.p.h. air velocity for tall shade trees.

This would require over 50 h.p. even if the fan were 100 percent efficient. What he could do separately to meet his claims was to add additional horsepower to turn the fan to an extremely high r.p.m. and reduce the size of the outlet to 8 to 10 inches. This would give 175 m.p.h. or greater velocity, while the air volume would drop to between 5,000 and 7,000 c.f.m., which is not a desirable combination for shade tree work. On the other hand, with terrific fan speed it could deliver 13,000 to 15,000 c.f.m. of air, but the velocity would be between 40 and 70 m.p.h., which is too weak for most users.

Absurd statements as to the extreme distance at which a particular machine is effective have influenced many buyers. With wind, drop size, and other things being equal, the distance of throw is determined by the air velocity and the square area of the outlet. At the same velocity, an outlet that is 11.3 inches in diameter will deliver twice as much air as one eight inches in diameter. A 24-inch diameter outlet will deliver four times as much air volume as one 12 inches in diameter and will require roughly four times as much horsepower. Outlets less than nine inches in diameter are not suited for most shade tree spraying when good coverage is required above 60 feet from the ground. Large machines may cover areas much faster than small ones, but they may not be able to maneuver as well in and out of difficult situations.

Mist Blower Specifications for Tall Shade Trees

Air volume: 8,000 c.f.m. or greater, depending on velocity.

Air velocity: 125 m.p.h. or greater for air volume of 8,000 to 10,000 c.f.m.; or 90 to 110 m.p.h. for air volumes of 20,000 to 30,000 c.f.m.

Diameter of Outlet: 12 inches *or greater*, depending on air volume.

Pump: To deliver at least 2 g.p.m. A plunger pump or a diaphragm pump is satisfactory for all mixtures and is preferred where wettable powder suspensions are to be applied at high pressure. A gear pump is satisfactory if only solutions and emulsions are to be used. A ½- to 1-inch gear pump is acceptable for wettable powders if pressures less than 20 pounds are used provided the pump turns less than 750 r.p.m. to reduce abrasiveness.

Delivery regulation: ⅕ g.p.m. to 2 g.p.m. with or without metering device.

Engine: Usually over 25 h.p., depending on performance.

Tank: 40 gallons or greater capacity, with suitable drain plug, and coated with material that is resistant to rust, corrosion, acids, and solvents.

Agitator: Mechanical agitation is preferred, especially where suspensions are to be used.

Outlet rotation: 210° arc is sufficient. Easily rotated mechanically or by hand.

Turntable: Required with a brake and capable of making a 360° turn easily Must be convenient for oiling, changing points, spark plugs, etc.

Shut-off valve: Quick-acting type, conveniently located to operator.

Turning diameter: Less than 9 feet.

Floor space: Less than 73 x 73 inches.

Weight: Less than 3,000 pounds.

Strainers: Suitable 16 to 20 mesh strainer for suspensions is necessary.

Atomization: Capable of producing mass average diameters between 35 and 80 microns.

Construction: Sturdy, durable, simple, easily operated, adaptable, and easily repaired and transported.

Location of seat and operator: Must be remote from the heat of the engine's exhaust and from leakage of air and spray material.

Mounting: For available trucks or mounted on a trailer.

Performance: Must meet efficient performance requirements for the jobs intended in addition to the above specifications.

A sheet of instructions on Methods of Operation and Maintenance must be supplied with the machine.

Mist Blower Application for Plantations, Pecans, Mosquitoes, Turf

PLANTATIONS: Mist blowers are not well suited for most plantations of large trees because of their inability to travel through the stands. The trees may be treated if they are small enough to permit mounting light-weight machines on tractors, or if they are planted in such a way as to provide roadways 30 to 100 feet apart. The width should depend on the size of the machine. The maximum roadway spacing for machines of 6, 12, 20, and 40 h.p. is approximately 30, 50, 75, and 100 feet. Many easy-to-kill defoliating insects may be controlled with two gallons of concentrate per acre of plantation. Other pests will require more.

In general, the requirements for plantations are similar to the ones discussed for nurseries. Use five gallons per acre for sawflies and defoliating insects. In well-stocked stands, 6 to 8x concentrations may be required for disease control with suspensions when using knapsack sprayers. Mealy bugs and scale insects may require 15 to 25 gallons per acre.

Nurseries and shrubbery: For insect control in good stockings, use 20x concentration for solutions and emulsions, and 12.5 gallons (10 to 15x) per acre for disease control.

PECANS: Pecans should be treated in the same manner as shade trees, using either mist blowers, hydraulic sprayers, or helicopters. Thorough coverage, especially at the tree tops is required for most insects and all diseases of pecans. A few species, like the fall webworm can be easily controlled with light dosages and low volumes. However, most insects and diseases require a 10x concentration for mist blower mixtures, using 2, 1.5, 1.0, and 0.5 gallons, respectively, of mixture per tree in the foliar period for trees 50, 40, 30, and 20 feet in height; and half these amounts in the dormant period. Thus far, airplane applications have not shown sufficient promise so they can be recommended other than for defoliators in large groves.

TURF: Mist blowers are adapted for treating turf and lawns to control insects crawling, resting, or feeding on grass and weeds like flies, mosquitoes, chinch bugs, cut worms, and Japanese beetles. They may also be used for making foliage applications to lawns and flowers of nutrients and liquid fertilizers such as Rapid-Gro, Nu-Green, Fer-Mel, potassium nitrate, boron, etc. The small units, like the wheelbarrow type, are suited for rolling over yards and small, difficult-to-reach places, whereas the larger outfits are better adapted for bigger areas such as golf courses. One operator treated 20 yards and 24 fruit trees per day with the wheelbarrow blower. The areas averaged 6,000 square feet. In making these treatments, it was necessary to know the area of the yard, the pests involved, the chemical formulations, and the volume to apply per 1,000 square feet or per acre.

For hand atomizers use of 4 to 6 gallons per acre (20x concentration is recommended.) From 5 to 10 gallons (10 to 20x) per acre is suggested for compressed air sprayers in the case of solutions, and 15 gallons per acre for wettable powders.

Caution: Mist blowers should not be employed to apply herbicides or other phytotoxic chemicals because of the drift hazard.

CONTROL OF MOSQUITOES AND GNATS:* Mist blowers are well adapted for outdoor application of larval and residual sprays. They give an effective coverage of 50 to several hundred feet depending on terrain, foliage cover, and the direction and velocity of wind. Yards, golf courses, recreation parks, camping grounds, flooded pastures, and woods are typical areas that may be treated with mist blowers. Often the light machines can be carried or transported into areas better than the heavier rigs which have to be mounted on trucks, trailers, or boats. Technics for drifting the spray into infested areas are discussed in Chapter II.

Usually two gallons of concentrate are applied per acre, containing the appropriate dose of insecticide, but this may vary somewhat with the toxicant selected.

Commercial Mist Blowers for Shade Trees and General Application

DESCRIPTIVE material, data, and several pictures of various commercial machines are given below. It is only part of the material that was supplied by manufacturers, and the writer does not attempt either to verify or refute their data and statements. Neither does the inclusion of this material constitute the endorsement of any particular machine. No claim is made that every manufacturer is included, but none have intentionally been omitted.

A list of the names and addresses of known American manufacturers is given so the potential user can write them for more complete information.

Listing for A. B. Farquhar Division

The Oliver Corporation, York, Penna.

This company makes two sizes of mist blowers. The larger of the two units (Model 125) is shown in Figure 27. Also, it makes a modification of the Model 125 rig with optional adaptations including high pressure plunger pump, mechanical agitation, small auxiliary gas engine, and hose and nozzle for applying dilute spray.

---

* Ground Equipment and Insecticides for Mosquito Control. American Mosquito Control Association. E. F. Knipling, Editor. Bull. No. 2, 1952.

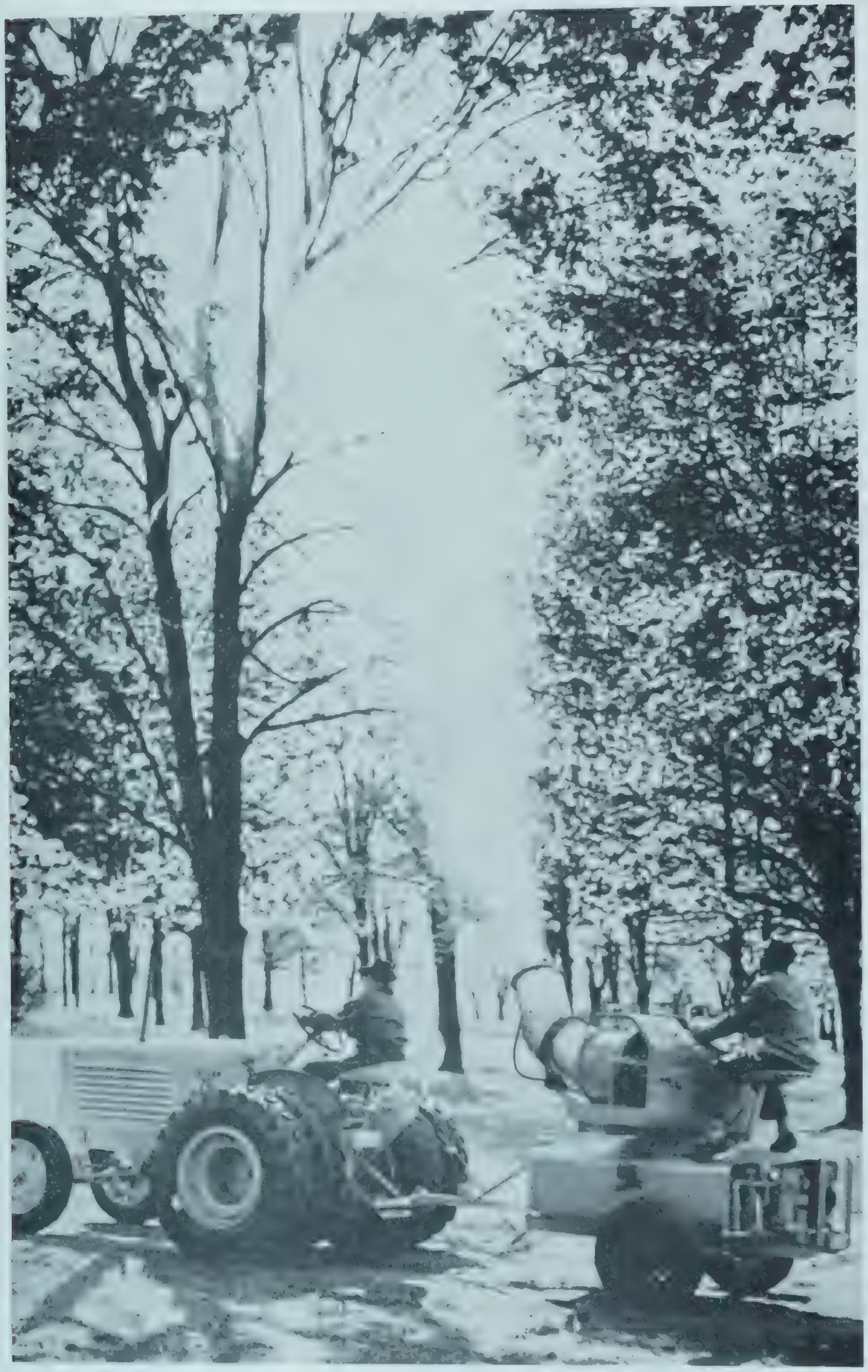


Figure 27. Shows A. B. Farquhar Model 125 Mist Sprayer treating trees in a park and woodlot. *Courtesy, The Oliver Corp.*

Farquhaar Model No. 125

Courtesy, The Oliver Corp.

Engine is a dependable, long life Wisconsin VE4, equipped with electric Starter and Generator. This four cylinder, air-cooled engine develops 35 h.p. at a normal operating speed of 2200 r.p.m.

Blower driven by V belts, is a Hartzell unit with solid cast aluminum alloy fan; axial-flow type, with heavy duty oversize ball bearings and shaft and straightening fins built into the steel barrel. The fan operates at an efficiency of 87 percent and delivers more air per h.p. than any other make. Since the speed is variable, the blower can be operated at speeds from 3000 to 4200 r.p.m. and at air capacity rates of 6000 to 11,000 cubic feet per minute, depending on the type and size of the air nozzle. Air velocity: 90-125 m.p.h. Outlets: 12 to 14 inches in diameter.

Air Nozzle with a 330° air direction angle, consists of a 13″ diameter tapered air nozzle mounted in a 14″ diameter right angle elbow, having 5 deflector vanes for efficient air transmission. It is operated by a conventional steering wheel. Controlled by a ⅛″ aircraft cable, it is easily turned from "up" to "down" position.

Pump, Hypro Model 750, handles all spray solutions. This pump has a capacity of 15 gallons per minute and insures satisfactory spray transmission and supply tank agitation. Relief valve is provided for regulating spray pressure.

Base consists of two steel channel skids with drilled holes for mounting bolts to mount sprayer on truck body. Tank is carried on these skids. The welded steel mount assembly is on top of the tank, supported by steel channels running lengthwise through the tank. The entire upper section rotates on a ball thrust bearing which is pressed into a rugged cast iron housing. A friction brake, controlled by a convenient foot pedal, locks the rotating head in any position of the 360° swing, enabling the operator to set the machine in a fixed position while operating or transporting. (Also allows slow rotation by "dragging" the brake.)

Tank has a capacity of 125 gallons. Hydraulic agitation is provided by overflow through unique piping arrangement. Thus, agitation begins immediately when the engine is started although blower is not engaged. Tank opening is 11⅝″ square and fitted with a strainer. The bottom drain pipe is threaded into the tank sump, and conveniently located for drainage.

Spray Heads are unique in their simplicity and effectiveness. Standard head consists of a grenade type body fitted with 4 stainless steel hollow cone type nozzles. In all spray heads, orifice rings or plates are quickly and easily changed in order to vary the gallon-per-hour rate.

Spray control is accurate. Pressure gauge and regulator are conveniently located for observing pressure and for adjusting regulator to control spray rate. Spray material stream is controlled by an easily-operated, quick-acting gate valve. All spray material passes through a strainer in the discharge line from the pump. Tank strainer is also provided for straining solutions and water into the tank.

Additional operating controls including a variable governor control, clutch lever, concentrate shut-off valve, pressure gauge and wheel which controls rotation of air nozzle, are located on the panel and can easily be reached from the operator's seat. A steel housing and grille enclose the operating parts of the unit, shielding the main belt drive, etc., and combine safety with modern streamlining.

Turntable: revolves in a 96-inch circle.

Weight is 1300-pounds empty.

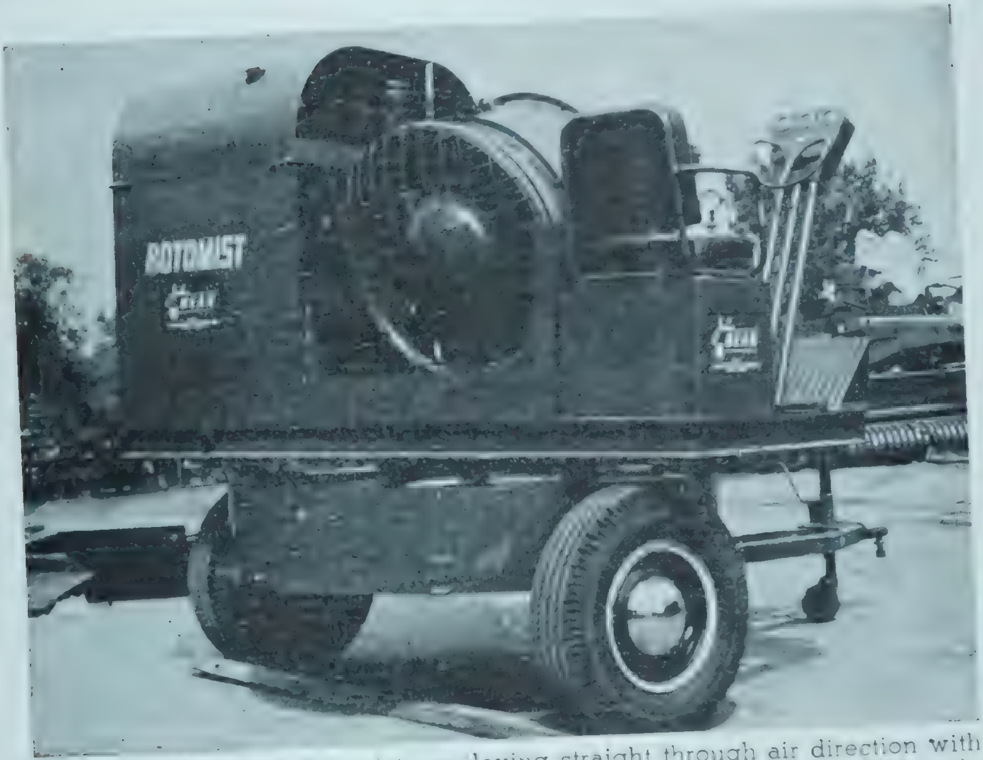


Figure 28. Model 100 Rotomist, employing straight through air direction with axial-flow fan delivering 28,000 cfm of air at 100 m.p.h. Rotates 360° right or left. Designed for mounting on a truck bed or hauling as a trailer unit.
Courtesy, Food Machinery Corp.

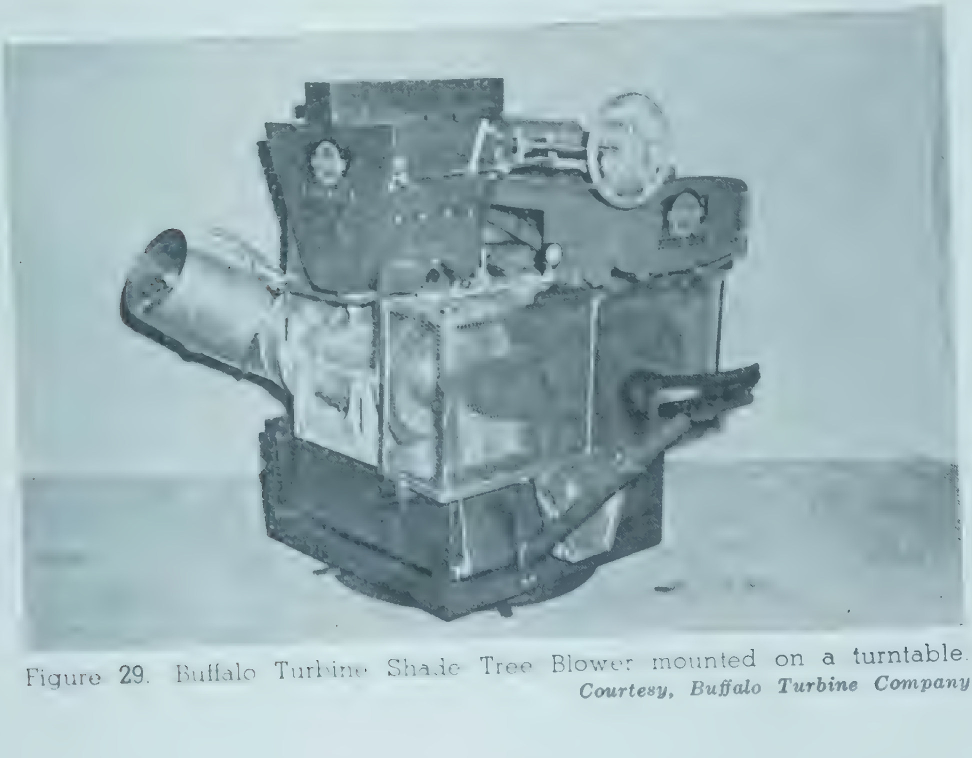


Figure 29. Buffalo Turbine Shade Tree Blower mounted on a turntable.
Courtesy, Buffalo Turbine Company

Listings for John Bean Division, F.M.C.

Lansing 4, Michigan

Condensed Specifications on John Bean Model 100 Rotomist (Figure 28)

Air Delivery Unit: Axial Flow Blower with air straightening vanes. Fan—29 inch 10-blade, balanced aluminum. Straight air delivery—28,000 c.f.m. at 100 m.p.h. Drive—through oil bath encloses gears with anti-friction bearings.

Power Unit: Engine—Liquid cooled, 4 cylinder gasoline (Willys). Delivers 40 h.p. continuous duty at 2600 r.p.m. Equipped with starter, generator, oil filter, oil bath, air cleaner, *automatic clutch* and 17 gallon fuel tank.

Spray System: John Bean Royalette enclosed pump, positive displacement type. Delivers 7 g.p.m. with adjustable pressure up to 400 p.s.i. Removable nozzles with changeable orifice size. Equipped with control valve, suction filter and pressure gauge.

Spray Tank: Reinforced circular flat heavy-gauge steel tank provides low center of gravity, stationary base. 100 gallon capacity, triple jet agitation. Splash-proof tank cover, filter screen and drain.

Operator Section: All controls conveniently near comfortable operator's seat. Aircraft type column and wheel easily directs outlet through 360° horizontally and 110° elevation from vertical to 20° below horizontal.

Hydraulic System: Package hydraulic system with complete controls power operates turntable rotation.

Construction and Mounting: Sturdy welded steel construction, with wide base and low center of gravity for great stability. Available for either truck mounting or with heavy duty trailer hitch and wheels for 7:00 x 15 tires.

General Specification:

Overall turning radius—52"
Dry weight, truck unit—2695 lbs.
Dry weight, trailer unit—3050 lbs.
Overall height, truck unit—68½"
Overall height, trailer unit—85½"
Diameter of stationary base—64"
Height—Base bottom to rotating frame—15⅜"

Listing for Model "F" Buffalo Turbine

Agricultural Equipment Co., Gowanda, N. Y.

This unit is furnished with or without a turntable and a dust attachment (Figure 29). It can deliver high velocities by driving the fan at high speeds and sufficiently restricting the diameter (square area) of the outlet.

A listing of the company is as follows:

Air volume: 1200 to 1400 c.f.m.
Air velocity: Up to 180 m.p.h.
Engine: Air cooled, Wisconsin VG-4, 36 hp.
Pump: Model 77—Single Diaphragm type, 6 g.p.m.
Tank: Stainless steel, 50 gallons.
Fan: Buffalo Turbine.
Air Nozzles: 2 furnished—1 round, 1 fishtail.
Liquid Nozzles: 8 furnished—4, ⅛" size; 4, ⅙" size.
Frame: Channel and "U" iron, electrically welded.
Carriage Guides: Roller bearings.

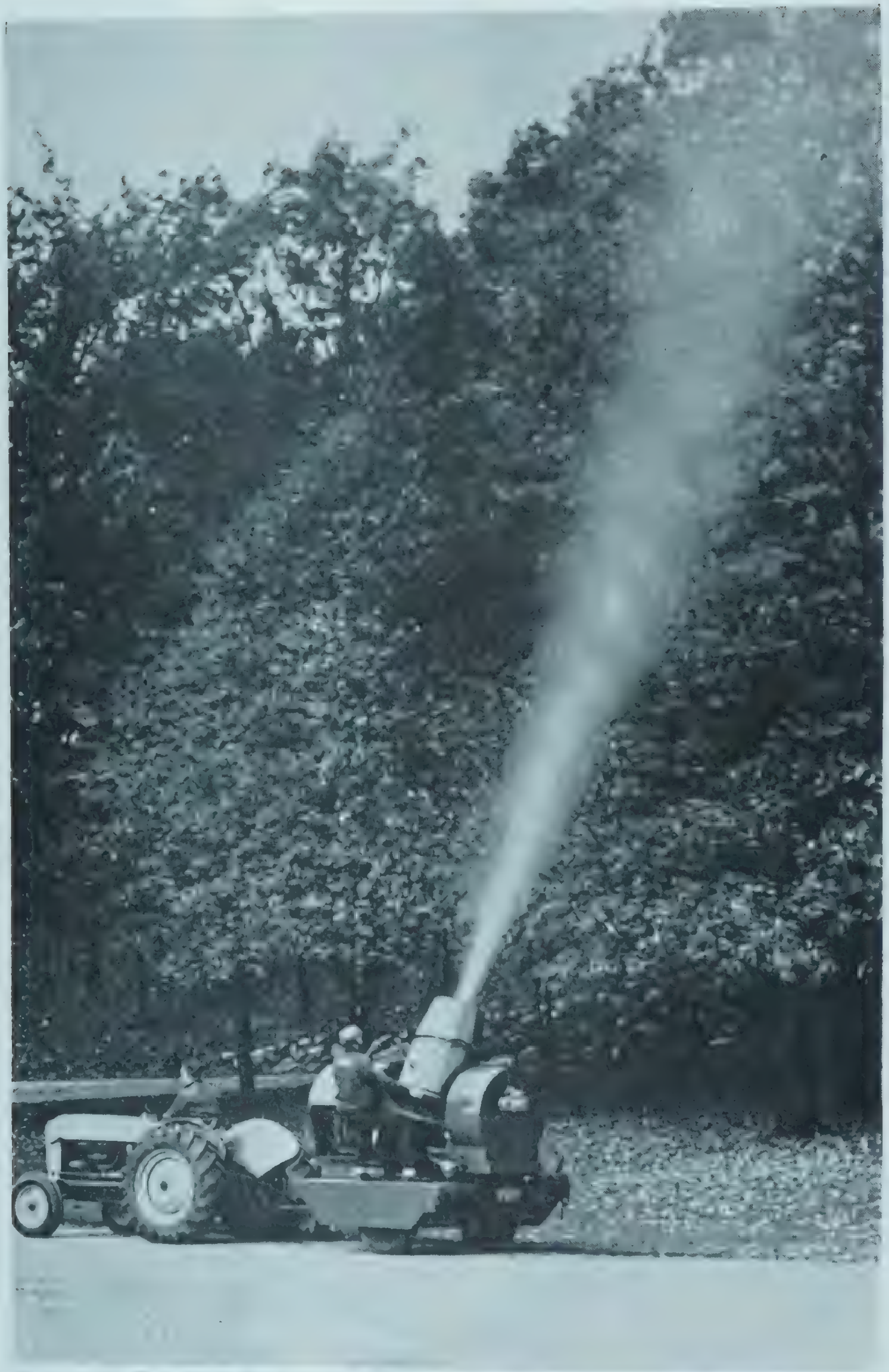


Figure 30. Rotomist 75 for truck or trailer mounting, powered with Wisconsin VF-4 engine. Straight through axial flow fan delivers 19,000 cfm of air at 100 mph

Courtesy, Food Machinery Corp.

Nozzle Rotation: 360°. Turntable Rotation: 360°.

Weight: 1480 pounds.

Dimensions:

Frame: 36" x 36"
Turning diameter: 52"
Height: 64"
Floor space: 34" x 34"

Specifications Covering the John Bean Model 75 Rotomist

Courtesy Food Machinery Corp.

Delivery Unit: Liquid Delivery: single nozzle with changeable discs, whirl plates and strainers. Air Delivery: 26 inch, seven blade axial flow aluminum fan with straight-through delivery discharging 19,500 cubic feet of air per minute. Fan assembly counterbalanced for effortless handling through a 110° arc, to 20 degrees below horizontal. Outlet, 20 inches in diameter.

Pump: John Bean Royalette 4, two cylinder positive displacement type pump. Capacity 4 gallons per minute at 400 pounds per square inch. Pump is completely enclosed with all working parts lubricated constantly by a bath of oil. Special "Sapphite" ceramic cylinders, diamond-honed for smooth, abrasive resistant surface and designed to handle continuously all types of spray materials. Equipped with air chamber, pressure gauge, cutoff and automatic relief valve with pressures adjustable from 0 to 400 pounds.

Tank: 75-gallon, rust-resistant steel tank. Filler opening is round, with a hinged, adjustable tension quick-clamp splash proof cover. All spray material is filtered leaving the tank through a Giant Star Shaped Bean Filter. High pressure jet-type agitation keeps material in a constant swirl.

Engine: 25 Horse Power, heavy duty air-cooled engine. Complete with air cleaner starter, muffler and generator. Automatic centrifugal clutch couples the engine to the fan. This clutch absorbs shock, limits vibration, protects the drive mechanism against overload shock when starting and stopping, and adds longer life to the engine, fan and transmission.

Drives: Engine to pump and to fan transmission by quiet operating, long lasting V-Belt. Fan operated through an enclosed right angle gear transmission.

Mounting: Electrically welded steel frame supporting the engine, pump and fan assembly pivots on a central balance point on a sturdy steel base with weight supported on rotating outer caster-wheels for stability. Trailer assembly with axle, wheels, drawbar, heavy duty ball-type hitch, and adjustable jack available at extra cost.

Dimensions: Turning radius 46-inches. Diameter of base on which unit rotates is 47-inches. Frame is 83-inches long. Net weight Skid Model approximately 1800 pounds. Trailer unit approximately 2260 pounds.

Guarantee: All John Bean Equipment is guaranteed to be of first class material and workmanship. Within a period of one year any part showing defects of material or workmanship will be replaced without charge. The limit of any such damage is the cost of the defective part.

---

* Condensed from material supplied.

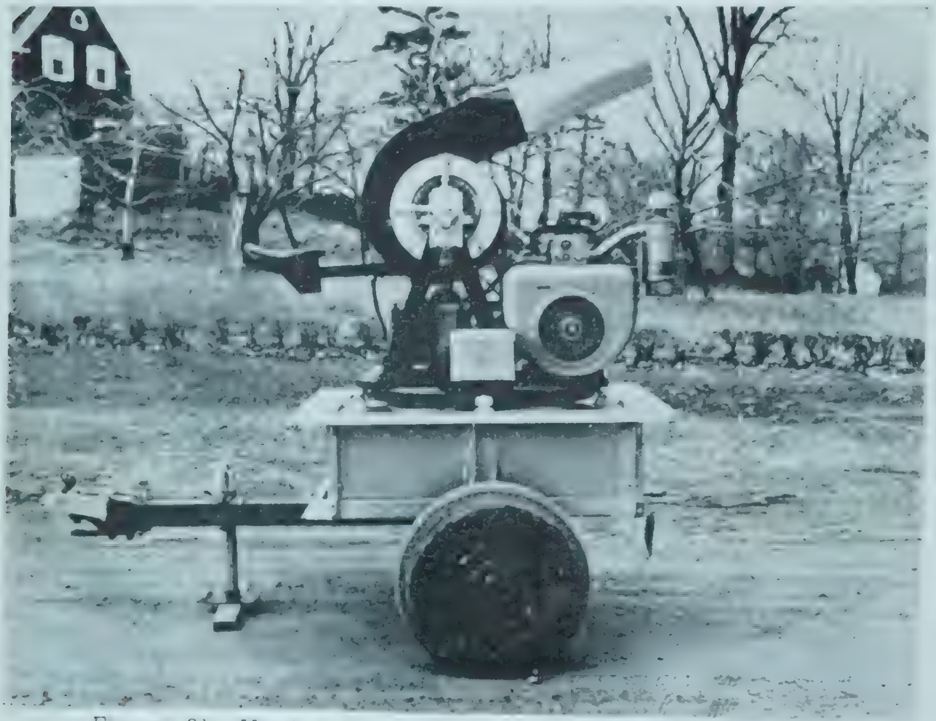


Figure 31. Hardie L40 mist blower mounted on a trailer.

Courtesy, Hardie Mfg. Co.

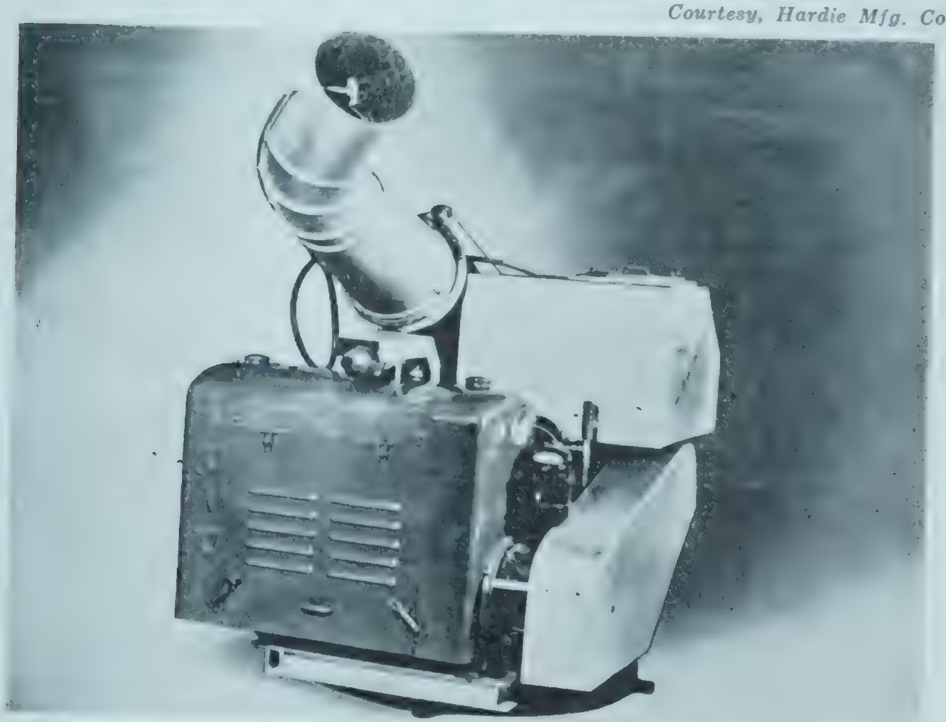


Figure 32. Hardie L80 mist blower for truck mounting on turntable, Hardie Mfg. Co., Hudson, Mich.

Courtesy, Hardie Mfg. Co.

Listing for Hardie Mfg. Co.

Listing for Hardie L40 light duty shade tree and general purposes machine (Figure 31), Hardie Mfg. Co., Hudson, Mich.

Engine: 20-22 hp. Wisconsin, air cooled.

Outlet: 8 inches, rotating type. Avoids making right angle turn of air.

Velocity: 140 to 150 m.p.h.

Turntable: 40 inch diameter, with V-shaped support.

Tank: Flat bottom with depression in bottom and mechanical agitation.

Weight off trailer: 1350 pounds.

Weight on: 1650 pounds.

Features: mounting on light vehicles, as ½-ton trucks.

---

* Condensed from material supplied.

Manufacturer's Listing for Hardie L80 Model

Hardie Mfg. Co., Hudson, Michigan

Specifications
Model L80

Air volume: 8000 to 10,000 cu. ft. per minute.

Air velocity: 150 to 160 m.p.h.

Diameter of air outlet: 12 inches.

Pump: Hardie Model No. 66.

Engine: Ford Industrial 48 hp. with starter, generator, battery, and clutch.

Tank: 53 gal. steel.

Agitator: Positive, mechanical.

Controls: All within easy reach of operator. Turntable, semi-automatic through 360 degrees. Air outlet, steering wheel control through 360 degrees. On and off valve to control spray material. Engine, throttle control. Clutch, to engage blower. Brake locks machine in any desired position.

Dimensions: Turntable diameter 40 inches.

Weight: 1500 pounds.

---

* Condensed from specifications supplied.

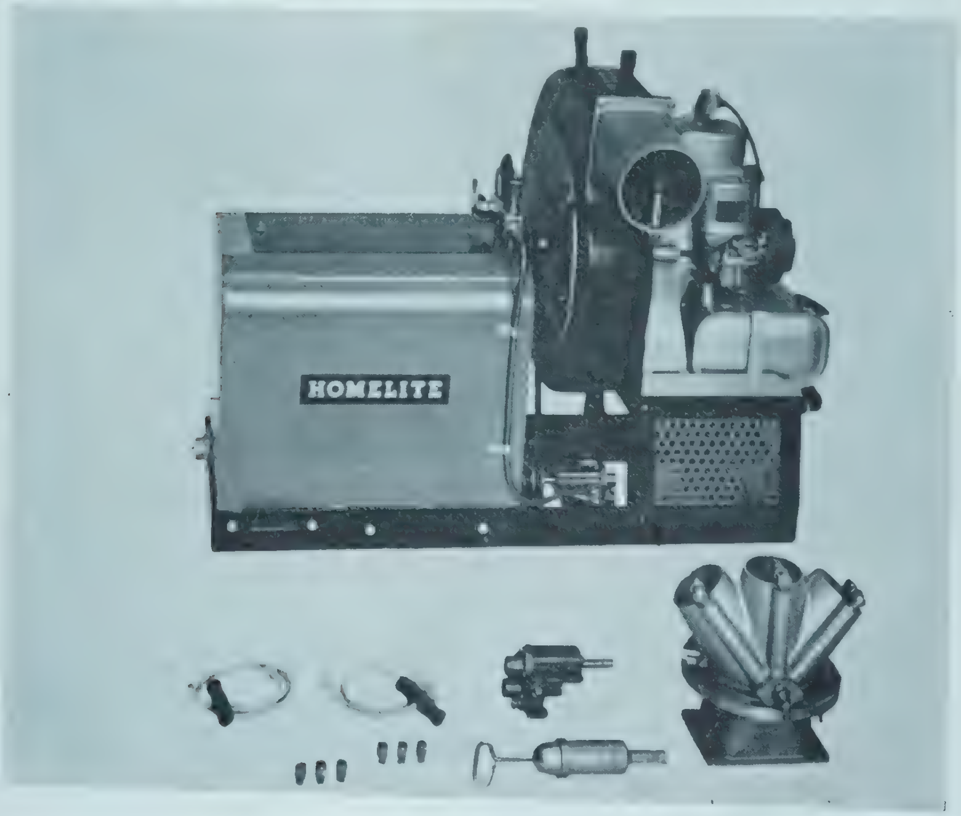
Lightweight 6 H.P. Mist Blower

THE specifications and need for a lightweight mist blower were made known to the Homelite Corporation. This resulted in their constructing a machine according to these specifications in 1949-50. The specifications and construction details for this machine are given below, together with results of some tests against pests. Since this machine may be manufactured and sold by any company, the details for construction and use are set forth for the benefit of potential manufacturers. Various sizes of this type machine, up to 15 h.p., weighing not more than 500 pounds, can be made.

Some information on the need for a machine of this type, its uses, and general physical requirements were published in a short Connecticut Agricultural Experiment Station Bulletin in 1953 (Potts, Spencer, and Friend). Copies of this Bulletin are not now available, therefore it seems advisable to quote the following paragraphs:

"The available shade tree and orchard type mist blowers are not well adapted for treating row crops, in addition to being too large and expensive. However, the air blast or mist blower type machine does offer certain distinct advantages over the above low pressure type equipment by being capable of (a) applying suspensions, (b) producing finer atomization, and (3) utilizing an air blast to carry and spread the spray stream and to agitate and penetrate the foliage. These features make possible a deposit of more insecticide on the undersides of the leaves, better coverage, and the use of fewer gallons of mixture per acre.

Figure 33 Mist blower with single, five inch diameter outlet and B3 whirljet spray nozzle attached in the center of the outlet. At the bottom of the picture are two series of 1/8 A1 and 1/8 A2 whirljet nozzles a pump and a triple hole outlet.



"Moreover, there has been a need for a light, multi-purpose mist blower in the 5 to 8 h.p. class which would apply concentrated spray materials efficiently and which could be readily mounted on farm tractors, small trailers, and pick-up trucks. Such a machine, weighing about 200 pounds empty, has now been developed. Its capacity of about 1,500 cubic feet of air per minute at 150 miles per hour velocity, is not enough to spray properly shade trees taller than 40 feet, or orchards of large area. However, the construction and design should adapt it for many uses, including the spraying of row crops, nurseries, low shade and ornamental trees, shrubs, small orchards, grapevines and blueberries, and also for broadcast spraying and mosquito control."

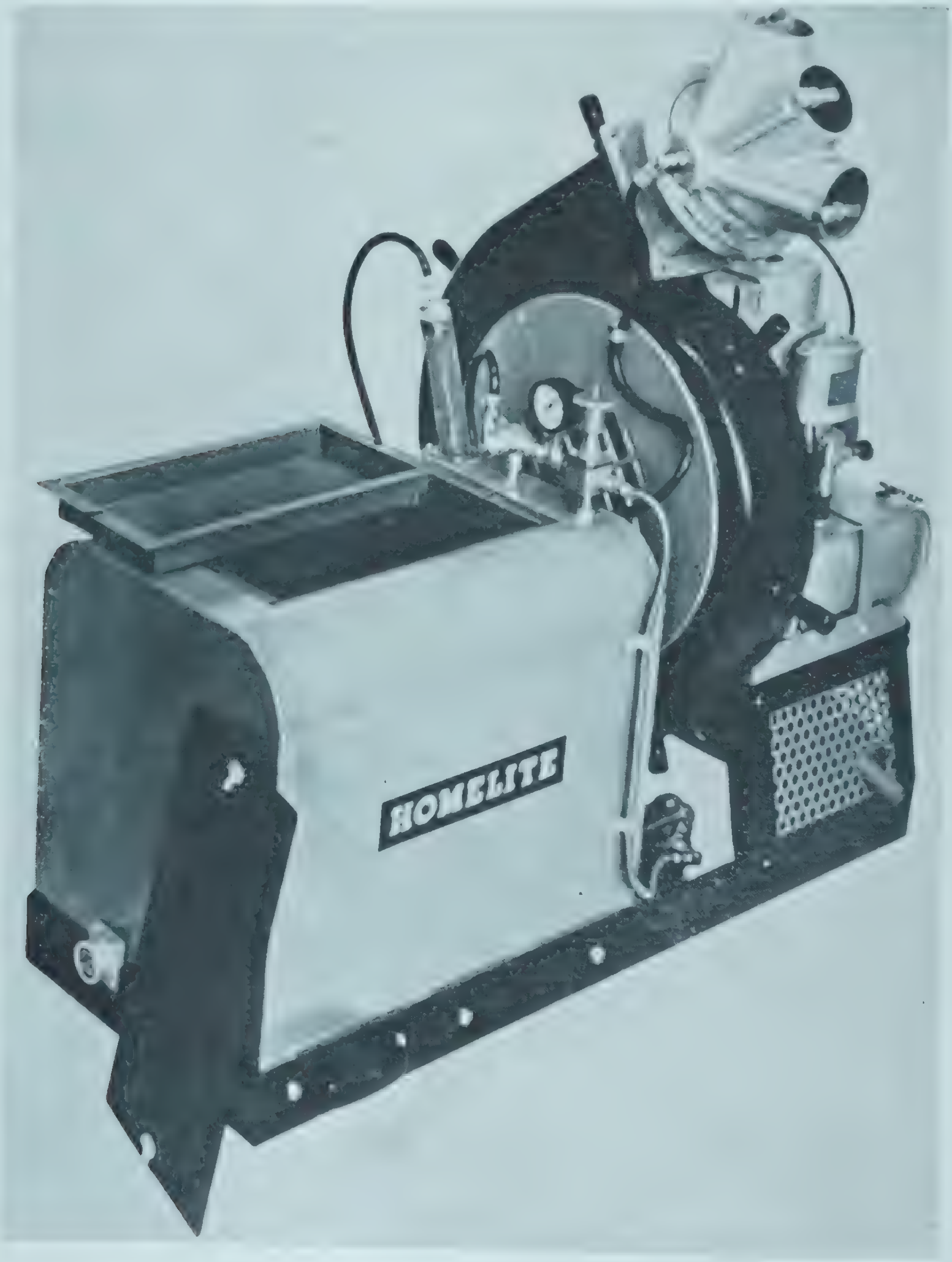
Description of Machine. The machine weighs 195 pounds and has a 20-gallon tank for spray materials. Its over-all measurements are 42 inches long, 27 inches wide and 32 inches high. The motor is a 6 h.p. Homelite air-cooled, two-cycle gasoline engine weighing 70 pounds, with a built-in speed governor set for 3600 r.p.m. The fan is a centrifugal type, 14 inches in diameter with 12 blades 4⅛ inches long. It is of cast magnesium and is mounted directly on the engine's drive shaft, which eliminates a belt and two pulleys and makes a more compact unit (Figure 33).

The fan delivers up to 1500 cubic feet of air per minute at 150 miles per hour. The fan housing and outlet can be rotated *vertically* on its stainless steel ball bearing mounting through a 200 degree arc. This permits direction of the spray at different angles from either side of the machine.

A pump and mechanical agitator may be driven at speeds up to 1500 r.p.m. by a single V-belt pulley on the engine's drive shaft. The inlet to the pump is through a flexible hose line on the end of which is a 16 mesh filter of large area. This line enters the top of the tank through a guide tube running to the tank's bottom. This arrangement permits easy removal of the filter and line for cleaning (Figure 34). The pump may be either a ¼ inch or ⅜ inch spur gear type with outboard bearing and mechanical seal, one of the newer oil and abrasive resistant Hypo roller types, or a 2 to 3 gallons-per-minute plunger pump, utilizing a speed reduction (third wheel) to reduce the pump speed to 100 to 300 r.p.m.

The gear pump is the cheapest type for applying solutions and emulsions, but may have to be replaced more than once during a season when applying wettable powder. The plunger pumps are the most durable ones and the roller pumps are intermediate between the gear and plunger types. Spray mixture in excess of nozzle output is by-passed back into the tank by means of an even-flow relief valve and pressure regulator that was developed for the machine.

Figure 34. View of mist blower, showing operating parts including frame, rotating fan housing, tank, pump, strainers, gauge, pressure regulator, and triple round outlet.



The tank has a "V" bottom, a wide-mouth filler-opening equipped with a 12 or 16 mesh removable strainer, and a suitable drain plug located at the bottom of one end of the tank. The tank's agitator is adequate for preparing mixtures in the tank. It has two curve-bladed bronze paddles mounted on a stainless steel shaft. The agitator shaft has a ball bearing and double seals at each end.

Adaptations. Significant requirements for making a mist blower efficient and adaptable for many uses and conditions include suitable shut-off valve, air outlets, spray nozzles, and facilities for mounting on a trailer (Figure 35).

SHUT-OFF ARRANGEMENTS. The quick-acting, lever-operated spray shut-off valve is conveniently located for the operator. When an operator and driver are required for spraying, the operator can use one hand for manipulation of the outlet and the other for quickly opening and closing the shut-off valve. The spray tank serves as a satisfactory seat for the operator so the construction of a special seat for him is not necessary.

TURNTABLE. A turntable consisting of an automobile tire rim, and hub is shown in Figures 36 and 37.

When mounted on a tractor, the rig can be placed in a handy position behind the driver so he can turn the spray on and off while driving. When mounted on a trailer, a rod must extend from the shut-off valve lever to a conveniently located hand lever on the tractor, as in the case of ordinary tractor-drawn orchard sprayers.

OUTLETS AND NOZZLES. In order to serve many purposes, it is necessary that the blower housing, to which the outlet is attached, be so designed as to permit attachment of three types of outlets (single round, multiple round, and fishtail). Moreover, provision is made for changing the included angle of spread of the multiple round and fishtail outlets. This is done by turning the outlet on the blower housing to give the angle desired. This angle is maintained by tightening two wing screws on the outlet.

A single 5-inch diameter round outlet (Figure 33) is used with a whirljet nozzle pointed against the air blast in the center of the mouth of the outlet. This nozzle position is also used for the triple round outlet. For multiple outlet manifolds, the nozzle orifice selected is smaller than for the single round outlet because the latter

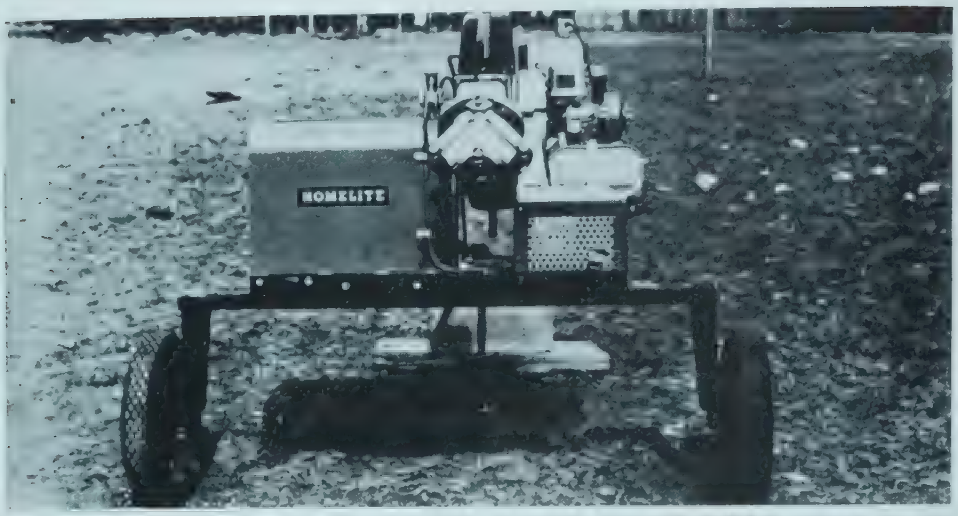


Figure 35. Trailer mounted mist blower with triple outlet pointed to the rear of the trailer. When the round outlet is to be used it is pointed at right angles to the line of travel of the trailer.

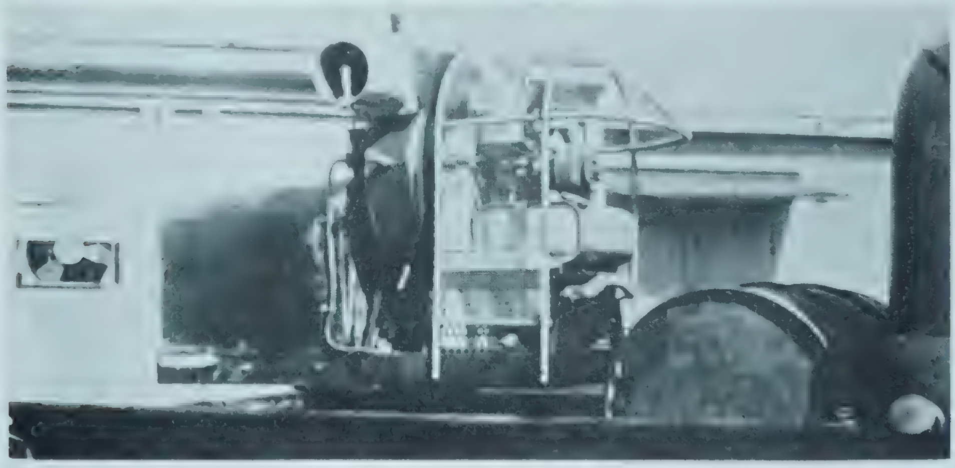


Figure 36. Machine mounted in a ½-ton truck on a turntable consisting of a tire rim and axle. The width of most ½-ton truck beds is 48 inches

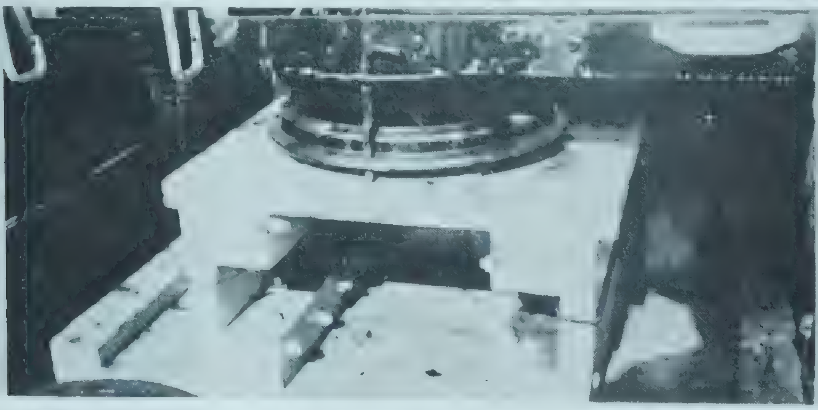


Figure 37. Showing turntable base with pin to lock machine when not spraying or when spraying from a fixed position.

Table 45. The volume of spray mixture delivered per acre using the triple outlet at a swath of 15 feet and 2.25 mph travel.

Nozzle	Pressure (p.s.i.)	Gallons per acre	Kind of mixture
Monarch oil burner nozzle	50	2.5	25% Kerosene emulsion
F80 No. 6.00	36	1.5	"
F80 No. 6.00	22	1.0	"
Monarch oil burner			"
nozzle F80 No. 12.00	50	5	"
"	36	3	"
"	22	2	"
No. 1 Whirljet	12	6	"
"	15	8	"
"	35	12	"
No. 2 Whirljet	10	12	Suspension of one pound
"	12	16	of talc per gallon of
"	35	24	water
"	40	28	"
No. 3 Whirljet	10	18	"
"	35	35	"
"	40	40	"

Potts, Spencer and Friend (1953).

Table 46. Numerical drop diameter obtained at 30 psi with different types of outlets and nozzles with engine going at full speed.

Type of outlet	Nozzle	Drop diameter microns
Single 5″ dia. outlet	No. 1 Whirljet (cone type)	38
Single 5″ dia. outlet	No. 2 "	44
Single 5″ dia. outlet	No. 3 "	50
Single 5″ dia. outlet	No. 5 "	55
Triple round outlet	No. 1 "	45
Triple round outlet	No. 2 "	52
Triple round outlet	No. 3 "	60
Large fish tail outlet	8001 Teejet (flat type)	70
Large fish tail outlet	8002 " "	82
Large fish tail outlet	8003 " "	88
Large fish tail outlet	8004 " "	96

Potts, Spencer and Friend (1953).

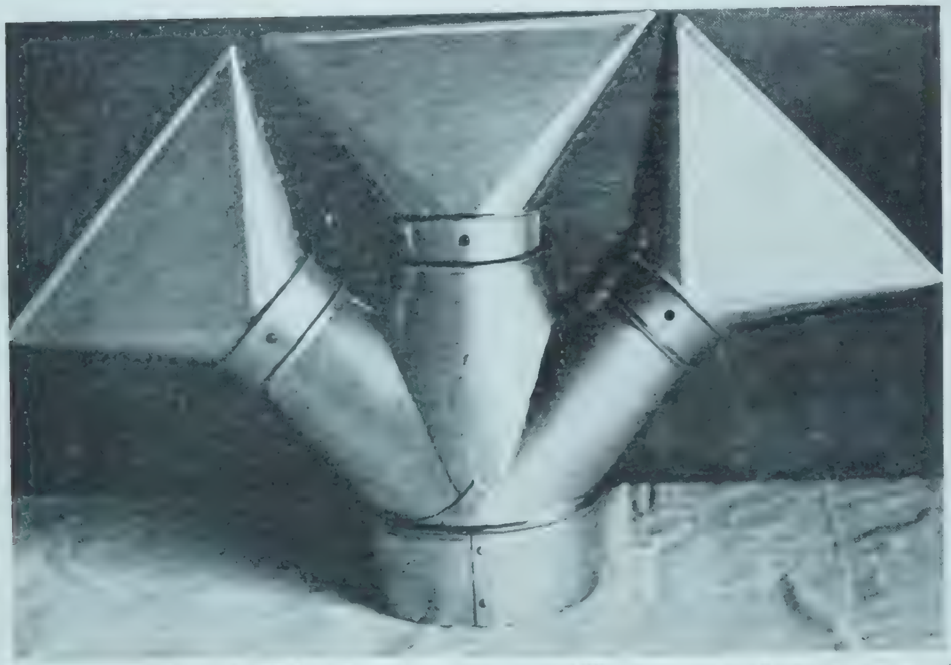


Figure 38. A triple fishtail outlet giving a 180 degree included angle of spread. The three fishtail outlets are attached to the three round outlets shown in Fig. 35 for treating close plantings of low trees.

Potts, Spencer, and Friend, 1953.

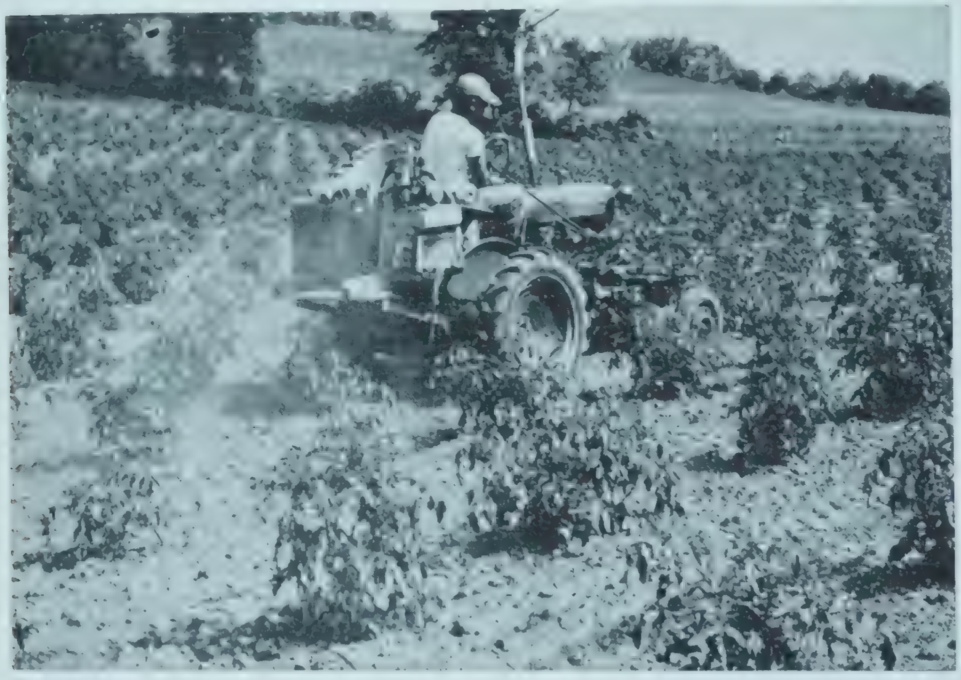


Figure 39. Mist blower mounted on a small tractor five feet above the ground for treating row crops. From this position the fishtail outlet can be used as well as the triple round outlets shown in the figure.

Potts, Spencer, and Friend, 1953.

delivers a greater air volume and treats a greater area than for any one of the outlets on the multiple outlet manifold. Nozzles are of hardened steel. The triple round outlet (Figures 34 and 35) has an included angle of spread of 80 degrees and each outlet is 2⅞ inches in diameter. It has the following advantages over the single fish-tail outlet: (1) driving the air to greater distances, (2) delivering a wider spray swath, and (3) producing a finer spray (Tables 46 and 47).

The fishtail outlet is 18 inches by one inch. Nozzles for this type outlet deliver the flat or fan type of spray stream. Examples of this type of nozzle are Tee jet nozzles 65067, 8001, 8002, 8003, etc. Three of these nozzles are placed 1½ inches above the top of the outlet and far enough back of the outlet's opening to permit the spray stream to spread the full width of the outlet where it meets the air stream. The effective swath width for the fishtail outlet is about 10 feet as compared to about 15 feet for the triple round outlet (Table 46).

A triple fishtail outlet can be effected by attaching a fishtail outlet over the end of each of the three round outlets (Figure 38). This arrangement gives a 180 degree angle of spread but it reduces the distance to which the spray can be driven. Hence, its use is most applicable to close plantings of low growing trees 4 to 12 feet tall and to growth conditions where branches overhang the spray rig.

Spray Delivery, Deposit and Drop Size Tests. To determine the machine's spray delivery rate and to test it for efficiency of operation, a number of mixtures were applied at different pressures through various types of nozzles and nozzle orifice sizes at rates ranging from 2.5 to 40 gallons per acre (Table 45). The data in this table are for the triple round outlet with one nozzle in each of three outlets. Two oil burner nozzles and the No. 1 Whirljet nozzle were used for solutions and emulsions. The oil burner nozzles are pointed in the direction of the air blast or at an angle to it, but never directly against the air blast.

Table 46 gives the drop diameters obtained when an oil of 45 seconds Saybolt viscosity is applied with various nozzles and pressures. Table 47 gives a comparison of swath width, number of droplets deposited per square millimeter, and the drop diameter for the triple round outlet as compared to the fishtail outlet.

Table 47. Comparison of swath width and number of droplets per square millimeter for the triple round outlet versus the fish-tail outlet with 20 p.s.i. at 3 m.p.h. travel, when applying a 25% oil emulsion.

Outlet type and nozzle	Average drop diameter microns	Slide No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Effective swath, about 15 feet																											
Triple, round, with No. 2 Whirljet nozzles	53*	No droplets per sq. m.m.	0	0.3	2.3	6	7	13	22	26	15	17	24	17	27	23	16	26	22	14	21	15	5	7	3	1	0
Effective swath, about 10 feet																											
Fish-tail with No. 8002 Teejet nozzles	82**	No droplets per sq. m.m.						0	1.2	3	8	10	13	9	14	10	13	9	10	8	7	4	2	0			

* Range, 8 to 165 microns.
** Range, 25 to 225 microns.

Potts, Spencer and Friend (1953).

Application to Row Crops with Light, 6 hp. Mist Blower

METHODS for treating row crops were reported by Potts, Spencer, and Friend (1953, pp. 7-8) as follows: "For treating tomatoes and beans the Homelite machine was mounted on a Farmall cub tractor (Figure 39) with its base three feet above the ground. This places the mouth of the outlets about five feet above the ground. The triple outlet was used with one No. 2 Whirljet nozzle in each outlet. It was pointed towards the ground at an angle of 15 degrees from the horizontal so that the air blast reached the ground at a distance of 10 to 12 feet from the sprayer. Twelve pounds pressure was required to deliver six gallons of mixture per acre at 2¼ miles per hour travel. This covered the area at 4.2 acres per hour with a swath sufficient to treat three 5-foot rows or five 3-foot rows. Visual observations indicated good coverage of sprayed vines as well as of glass slides that were placed on the ground and suspended among the plants. For best coverage of taller plants, it was found advisable to raise the machine on the carriage vehicle because the mouth of the outlet should be at least 2½ feet above the tops of the plants.

"Towards the end of the season the rank growth of tomato vines completely covered the middle of the rows. Therefore, since no vine lifters were available, a very late treatment could not be made without appreciable plant damage. A partial solution of this problem seemed to be the treatment of 30 to 35 foot strips (swaths) from two opposite sides using the single, round outlet. In this procedure the outlet discharges at right angles (perpendicular) to the line of travel of the mist blower. This reduces vine damage by about half. A better remedy, when using the single outlet in the above manner, would be to leave unplanted one tomato row in every 6 or 7 to serve as a roadway for the machine.

"Table 48 shows the degree of effectiveness of certain mixtures applied to control the potato aphid *(Macrosiphum solanifolii)* on eight acres of tomatoes. Table 49 indicates the degree of Mexican bean beetle *(Epilachna varivestis)* control, on four, one-fourth acre plots of beans. In addition, a ¼ acre bean field infested with adults and larvae was treated with Dilan emulsion at the rate of eight ounces of actual Dilan in six gallons of mixture per acre. This application gave approximately 95 per cent control and was more effective than the Marlate treatment."

Table 48. Reduction of aphids (**Macrosiphum solanifolii**) on tomatoes by the application of concentrated sprays, using the triple round outlet and a tractor speed of 2.25 m.p.h.

Field No.	Material applied in 6 gallons of water per acre	Number of aphids per sample of leaves before treatment	Percent reduction in number of aphids in treated as compared to check, 3 days after treatment
1	1 pint of nicotine sulfate		
	6 lbs. of copper oxychloride	2250	75
2	2 pints of nicotine sulfate	2700	86
	6 lbs. of copper oxychloride	3250	
3	1 pint of hexaethyltetra phosphate		
	6 lbs. of copper oxychloride	3250	99
4	1 pint of lindane (20% gamma)		
	6 lbs. of copper oxychloride	2650	97
5	1 pint of lindane (20% gamma)		
	6 lbs. of copper oxychloride	1850	95
Check	No treatment	2850	0 (3000 aphids per sample)

Potts, Spencer and Friend, 1953, p. 8.

It is difficult to apply accurately less than five gallons per acre of mixture containing wettable powders with this equipment. However, when applying solutions and emulsions the oil burner, cone type nozzles can be used to apply rates from one to five gallons per acre. These nozzles should point with the air blast. Most truck crops require 4 to 10 gallons per acre.

Excellent control of strawberry diseases and insects was obtained with the above machine using 10 to 20x concentrations at six to 10 gallons per acre.

Cornell Row Crop Mist Blower

BRANN and Gunkel (1953) developed another type machine for crops (Figure 40).

The distribution system consists of four round rotating outlets mounted on a turret head. Each outlet is six inches in diameter, necked down to five inches on the discharge end. These individual outlets are connected to the main head by a short piece of flexible hose and two pivoted arms. This hinged arrangement permits the vertical adjustment of the outlets.

A liquid nozzle is located in the center of each individual outlet. These nozzles are of the spring-loaded poppet type and are non-clogging. Stainless steel is used in their construction to prevent rapid wear by the abrasive spray materials.

Table 49. Mexican Bean Beetle (**Epilachna varivestis**) population before and after treatment in 4 plots treated at the rate of 4 pounds of 50 per cent Marlate wettable powder in 6 gallons of water per acre and a tractor speed of 2.25 m.p.h.

	Total number of bean beetles in four, twenty foot linear samples						Per cent Defoliation	
Plot No.	At time of treatment			10 days after treatment			At time of treatment	per cent increase in defoliation 10 days after treatment
	*Adults	Egg Masses	Larvae	*Adults	Egg Masses	Larvae		
1	13	4	76	1	0	2	4	0
2	3	12	104	0	1	3	5	0
3	24	7	189	4	1	7	5	0
4	15	9	217	2	0	10	7	0
check	10	6	122	12	23	380	5	20

* Includes pupae.

Note. Dilan, parathion, and malathion were later found to be much more effective than Marlate against the Mexican bean beetle, using 4 to 6 gallons of mixture per acre.

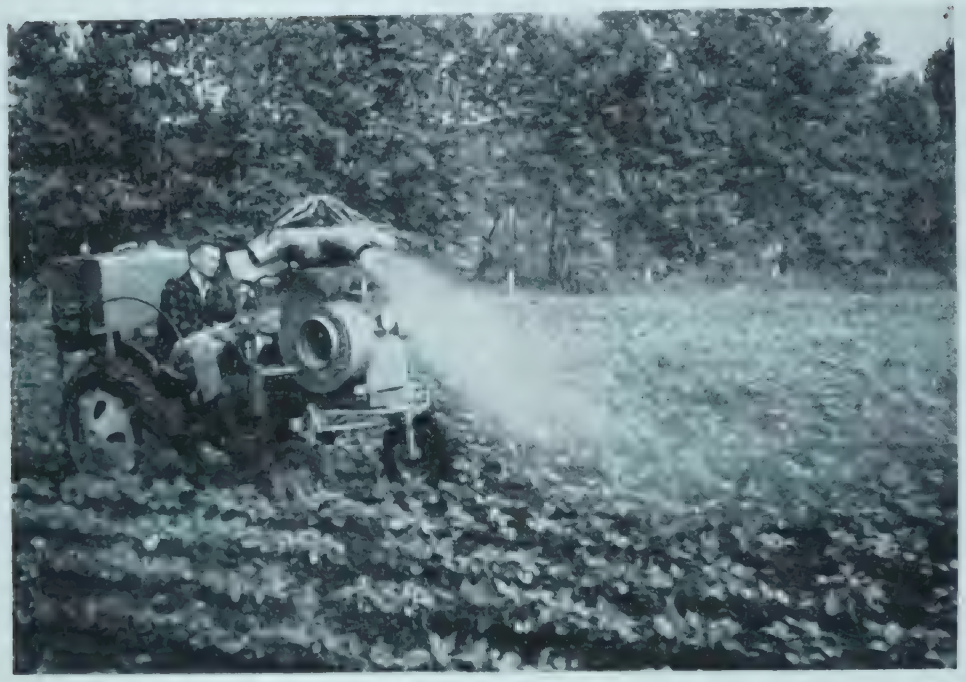


Figure 40 Row crop machine with overhead rotating outlet developed at Cornell by Brann and Gunkel

Brann and Gunkel, 1953.

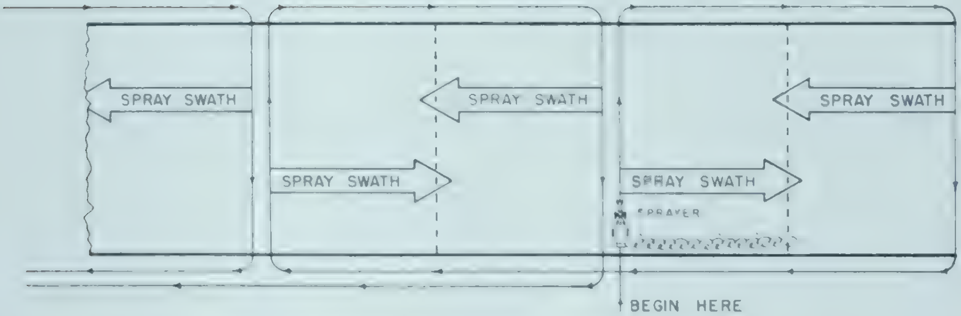

SPRAY SWATH
SPRAY SWATH
SPRAY SWATH
SPRAY SWATH
SPRAY SWATH
SPRAYER
BEGIN HERE

Figure 41 Diagram illustrating swath coverage of spraying row crops and fields from two opposite sides with 14 to 50 hp machines.

The machine is further described by Brann and Gunkel (1953) as follows: "The fan delivers to the turret approximately 4000 c.f.m. of air, which is discharged through the outlets at 150 m.p.h. during the forward 180° of rotation. The liquid is injected into the air stream at 20 to 40 p.s.i. during the forward 120° of rotation. The swath pattern is laid down in a series of cycloidal curves as the machine moves forward. Thus when the sprayer is driven at two m.p.h. and the head is rotating at 15 r.p.m., a swath of mist six to eight feet wide is laid down every 2½ to three feet.

"In the first tests with the machine the mist appeared to be carried 20 to 24 feet on each side of the machine. However, an examination of leaf prints and residue analysis, as well as an experiment on bean beetle control, showed the effective swath width to be one-half this distance. . . . The deposits were fairly even for four rows on each side of the machine and then dropped off rapidly. Bean-beetle-control data were taken from a similar test in which parathion was applied at the rate of ¾ pint per acre, and show a drop in control beyond the fourth row. When driving the machine back and forth across the field at 7-row intervals the swaths were overlapped. In this way all of the plants are sprayed from two sides, which tends to give uniform coverage on the undersides, as well as top sides, of the leaves. Hence, the distribution was fairly uniform across the seven rows. Results indicate that excellent bean-beetle control can be obtained by using a pint of 25 percent parathion emulsion per acre in as little as 5 gallons of water.

"Other experiments conducted in 1951 and 1952 have yielded encouraging results in the control of bean beetle, potato flea beetle, and onion thrips, using from 5 to 20 gallons of water per acre."

Large Row Crop Mist Blower Equipment

THE conventional use of two or three spray nozzles per row is not practical for applying concentrate suspensions because, if the orifices are sufficiently large ($^{1}/_{16}$ to $^{3}/_{32}$ inch) to avoid clogging, at least 50 gallons of mixture may be applied per acre. If the size of the orifices and the pressures are reduced to lower the spray delivery, clogging will result. A remedy for this problem would seem to be the distribution of the output of each liquid nozzle over more than one row, using air from the spreader outlets. The machines should travel 2.5 to 5 m.p.h., the rate of mixture applied per acre being in inverse ratio to rate of travel.

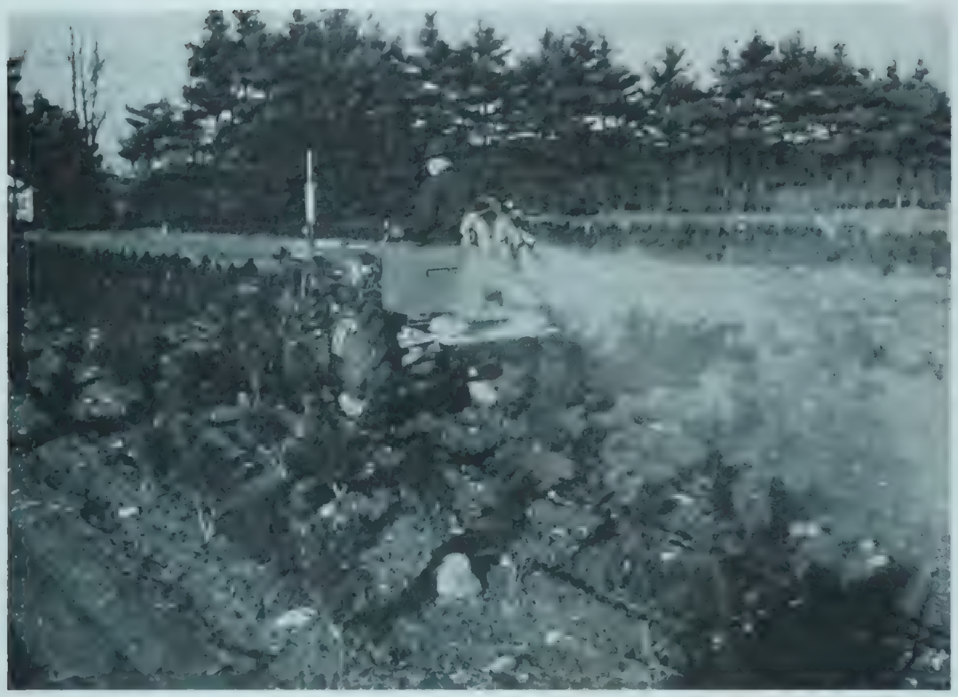


Figure 42. Treating six 30-inch rows of nursery stock with mist blower mounted 4 feet above the ground on a small tractor.

Potts, Spencer, and Friend, 1953.

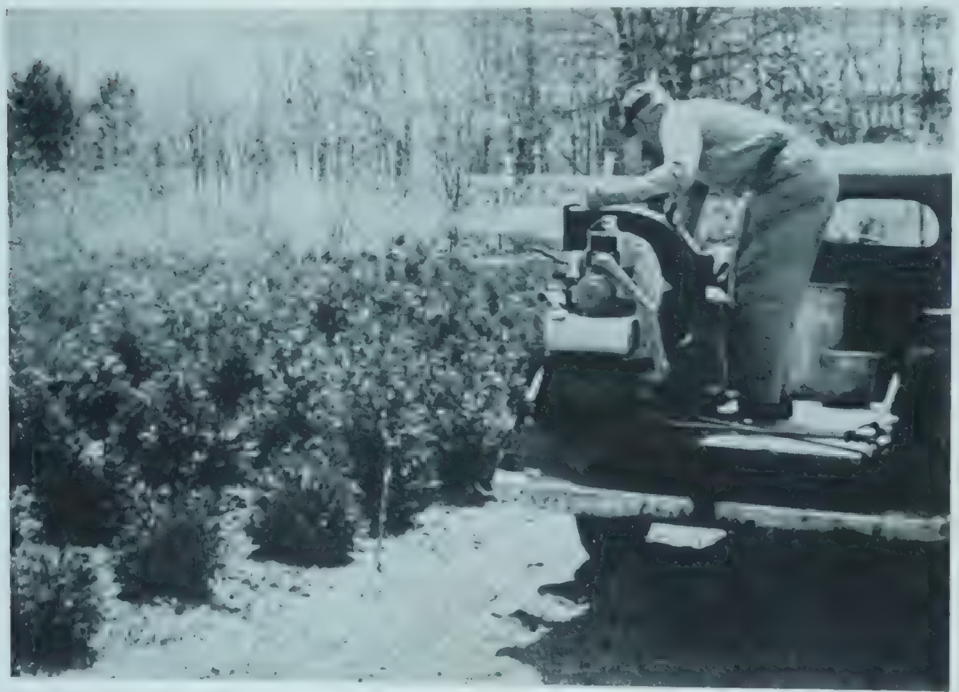


Figure 43. Treating nurseries with the machine mounted in a half-ton truck, using a single, round outlet.

Potts, Spencer, and Friend, 1953.

Rapid coverage with low gallonage should be possible in two ways. First, by using a round outlet containing one or more liquid nozzles to deliver spray at right angles to the line of travel. For instance, machines delivering air at 3,000 c.f.m. or more are mounted at least three feet above the ground so that sprays will be delivered to a considerable distance. With this arrangement, 15- to 75-foot strips (5 to 25 three-foot rows) are treated from two opposite sides. The width of the strips covered depends on the size and capacity of the machine. The larger outfits may over-shoot three to five rows nearest to the machine with a single round outlet. However, this can be remedied by using a deflector or spoiler to deflect downward at least a portion of the mist from one nozzle onto the rows close to the blower. Thus far, this method has been promising for insect and disease control when delivering as little as 4 to 7 gallons of concentrate per acre.

Various commercial machines are now designed with outlets, for covering foliage close to the machine while delivering most of the air and spray to considerable distances from it.

Figure 14 shows a three-hole outlet designed by the author for use on 12 to 40 h.p. mist blowers for treating crops and nurseries, and for broadcasting. The two smallest outlets cover areas close to the machine, while the large outlet is delivering spray beyond the areas covered by the two smaller ones. The outlet should be constructed to discharge ⅛ of the total air volume through the small lower outlet for coverage close to the machine; ¼ of the total air volume through the center outlet; and ⅝ of the total air volume through the top outlet. The amount of spray delivered through each outlet should be in relation to the amount of air delivered through it.

Treatment for Nursery Pests with 6 hp. Light-Weight Mist Blower

FOR treating row plantings of nursery stock three feet or less in height, (Potts, Friend and Spencer, 1953) the blower was mounted on a Farmall cub tractor about four feet above the ground, with the triple outlet pointed towards the ground at an angle of about 15 degrees. This angle should be increased or decreased slightly with increase or decrease in the height of the machine above the plants.

Five, 36 inch rows or six, 30-inch rows can be covered with the machine traveling 2 to 2½ miles per hour. Coverage has been good with winds up to 12 miles per hour. When the wind dropped to less than 10 miles per hour, five 30-inch rows (or four 36-inch rows) could be covered at four miles per hour travel.

Where the plants are more than three feet tall, it is necessary to use the round outlet and treat strips of rows from two opposite sides. Strips up to 30 feet in width can be treated with this machine (Figure 43).

RED MITE TESTS IN NURSERIES. During 1950 and 1951, 16 plots comprising about 12 acres of nursery stock of arborvitae, hemlock, spruce and yew in Connecticut and Rhode Island were treated with the following miticide mixtures for control of the spruce mite, *Paratetranychus ununguis* jacobi, and the two spotted mite, *Tetranychus bimaculatus* (Harvey).

Aramite, Ovex and DMC gave about the same results at the dosages listed below. Usually one application was enough in Connecticut, but under Rhode Island conditions more than one application was required. Mite conditions at Newport, Rhode Island were so severe that it may be advisable to increase the dosage listed above

Per acre quantities:		Per cent reduction in mites over check after 5 days
I. Aramite (50 per cent emulsifiable concentrate)	2 pints	
Kerosene	2 quarts	95
Emulsifier (as Triton X-100 or the equivalent)	3 ounces	
Water to make 6 to 8 gallons		
II. Emulsifier DMC (25 per cent DMC)	2 quarts	
Water to make 6 to 8 gallons		93
III. Ovex (20 per cent emulsifiable)	5 pints	
Water to make 6 to 8 gallons		92
IV. DMC (25 per cent emulsifiable)	3 pints	
Ovex (20 per cent emulsifiable)	3 pints	
Water to make 6 to 8 gallons		98
V. Aramite wettable powder containing 15 per cent Aramite		
Water to make 6 to 8 gallons	7 pounds	86

by 50 per cent. A combination of Ovex with either DMC or Aramite is superior to either compound applied alone. The combination of DMC and Ovex was effective for an entire season with one application. The liquid forms of Aramite and Ovex were less apt to clog fine nozzles and were compatible with more different insecticides than the powdered forms.

Emulsifiable DDT was used for control of scale insects, the gypsy moth and Japanese beetles in combination with the above miticide mixtures in quantities up to two pounds of actual DDT per acre without causing an appreciable buildup of mite population.

The most practical volume of mixture for applying a given quantity of insecticide per acre of nursery stock will vary more with the size, activity and habits of the pest to be controlled than any other factors. For average conditions, estimates of the number of gallons of mixture per acre suggested for the following pests are as follows: gypsy moth, 2; Japanese beetle, and gross feeders, 3; red mites, 6 to 8; scale insects, mealy bugs and small inactive forms that live at the lower part of the tree on or near its trunk, 10 to 15; and 15 to 20 gallons for diseases. Concentrations for the above gallonages in terms of the conventional mixture would be 100x, 66x, 25x to 33x, 14x to 20x, and 10x to 14x.

Mist Blower Treatment of Field Crops and Pastures

CORN. Application to corn encounters the same problems as just described for cultivated blueberry bushes (page 197). When the corn plants are small it is easy to go through with tractor mounted mist blowers, but when the plants are tall this type of treatment becomes difficult. When available, mist blowers can be mounted on self-propelled high clearance and detasseling chassis (see section on low gallonage, high clearance machines for corn). From 5 to 10 gallons per acre has given good control for most insects, excepting the difficult to control ones like the corn ear worm.

COTTON. As far as the writer knows, no detailed experiments have been conducted on cotton with mist blowers that were properly designed for the job. The type best suited is the 6 h.p. row crop type shown in Figure 39. This type is best suited for small fields, since its coverage is limited to about 30 acres per 8-hour day. Large acreages would require a larger machine (12 to 15 h.p.) of this type or more than one of the six h.p. units. Another possibility is the use of the large commercial broadcast type machines to treat 50 to 100

Commercial Air Blast Concentrate Machines For Vegetables, Field Crops, and Pastures

Descriptive material, data, and several pictures of various commercial machines are given below:

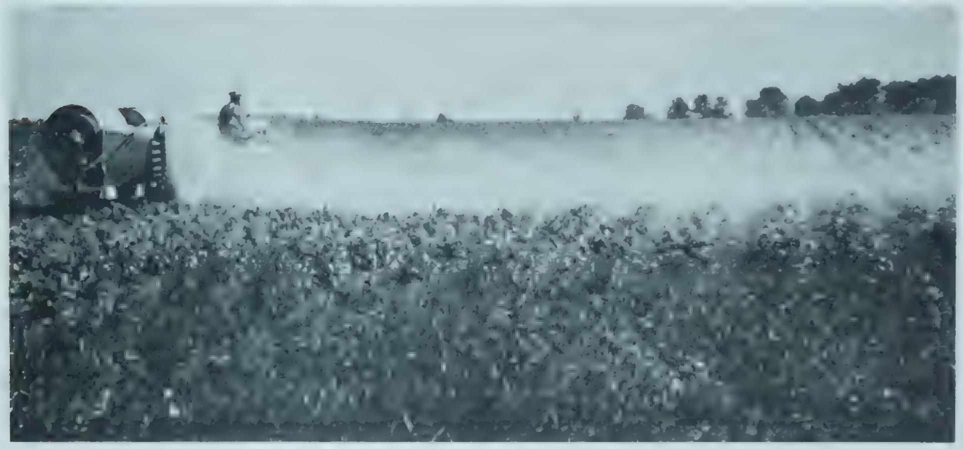


Figure 44. F. E. Myers row crop concentrate sprayer with 74 hp engine, 13 gpm high pressure pump and air delivery of 26,000 cfm at 90 mph. Has adjustable outlet rotation, and deflector vanes.

Courtesy F. E. Myers & Bros. Co.

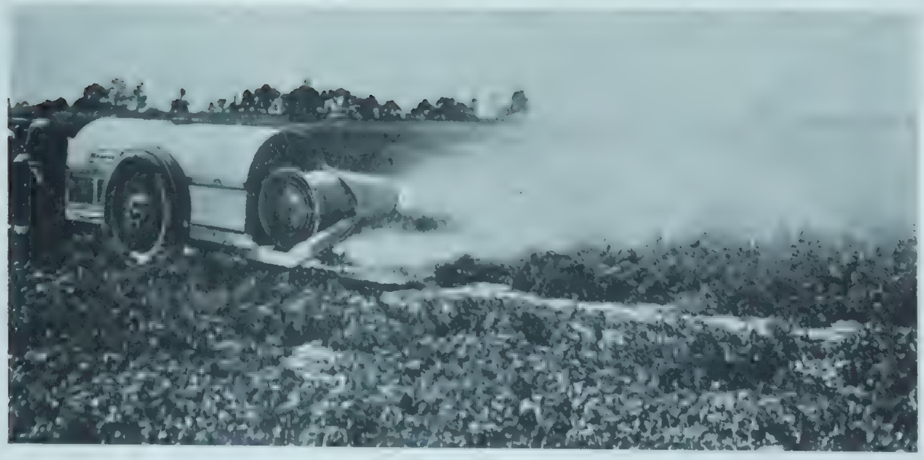


Figure 45. Hardie Jetaire air-blast row crop sprayer.

Courtesy, Hardie Mfg. Co.

acres per day as pictured and described in the section on commercial row and field crop mist blowers. Some of these big rigs would have difficulty getting through rank cotton.

For cotton, the mist blowers would have to compete with dusters and low gallonage equipment now in use. The latter are cheaper than mist blowers. However, it is not generally realized that mist blowers have the following advantages: (1) they can control such diseases as may be controlled by fungicide application, (2) they can apply suspensions of wettable powders like sulfur and calcium arsenate, and (3) they can effect control with less volume of spray mixture per acre, and (4) they are adapted for a multitude of uses.

PASTURES, CLOVER, AND SMALL GRAIN FIELDS. May be easily treated with mist blowers, but the advisability of treatment may depend on whether the machine can travel without causing excessive damage to plants and soft ground. Usually pastures can be treated without difficulty and the same is true for old clover fields, if they are sprayed before the clover is too tall to be seriously damaged by wheels of the blower or its carriage vehicle. When plants are small and low, grain fields may be readily treated provided the ground is not soft or muddy. The light weight machines of 6 to 15 h.p. capacity cause the least damage and are best for small, irregular-shaped fields. The above fields may be covered very rapidly by mist blowers. From 20 to 300 acres have been treated per day depending on the size of the machine, the number of gallons applied per acre, and the number and size of the fields.

Hardie Jetaire Air Blast Row Crop Sprayer

The new Hardie Jetaire Sprayer provides a complete air blast unit for application of concentrate and dilute sprays to tomatoes, potatoes and all row crops.

The discharge housing is fully reversible, rotating through 220 degrees, giving the operator absolute and complete control of spray direction and pattern. It functions equally well on either side. The Hardie Jetaire is delivered complete, ready to operate. Treads are adjustable from 60″ to 72″ in width. Ground clearance is adjustable from 12″ to 20″.

Two exclusive Jetaire features are of exceptional value to the grower. One is the dual fan equipment of the unit. Two, 20 inch Hardie axial flow fans provide supercharging action, assuring ample air volume and velocity at all times and under all conditions. The

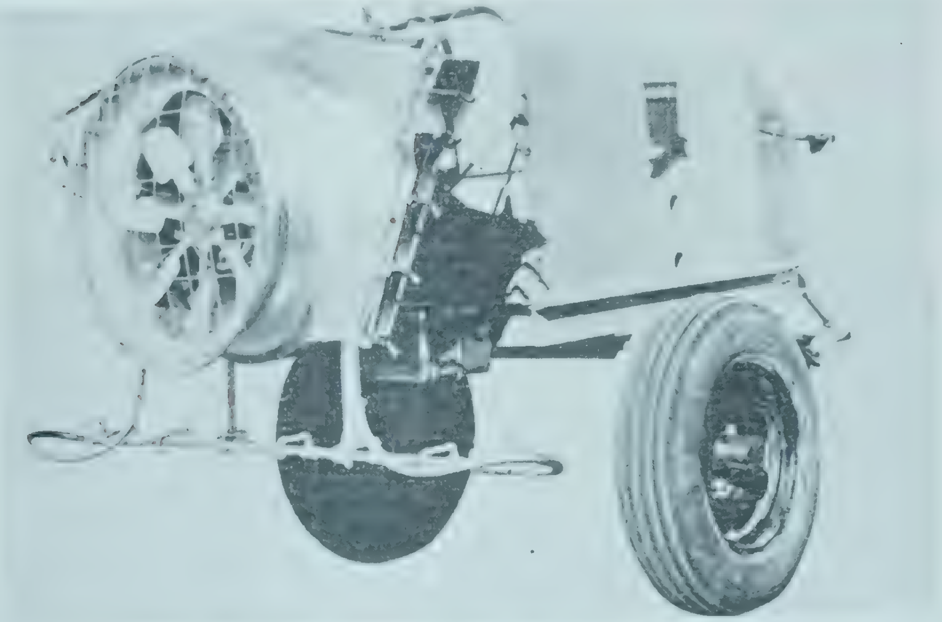


Figure 46. Iron age, air blast row crop unit, York, Pa.

Courtesy of The Oliver Corp.

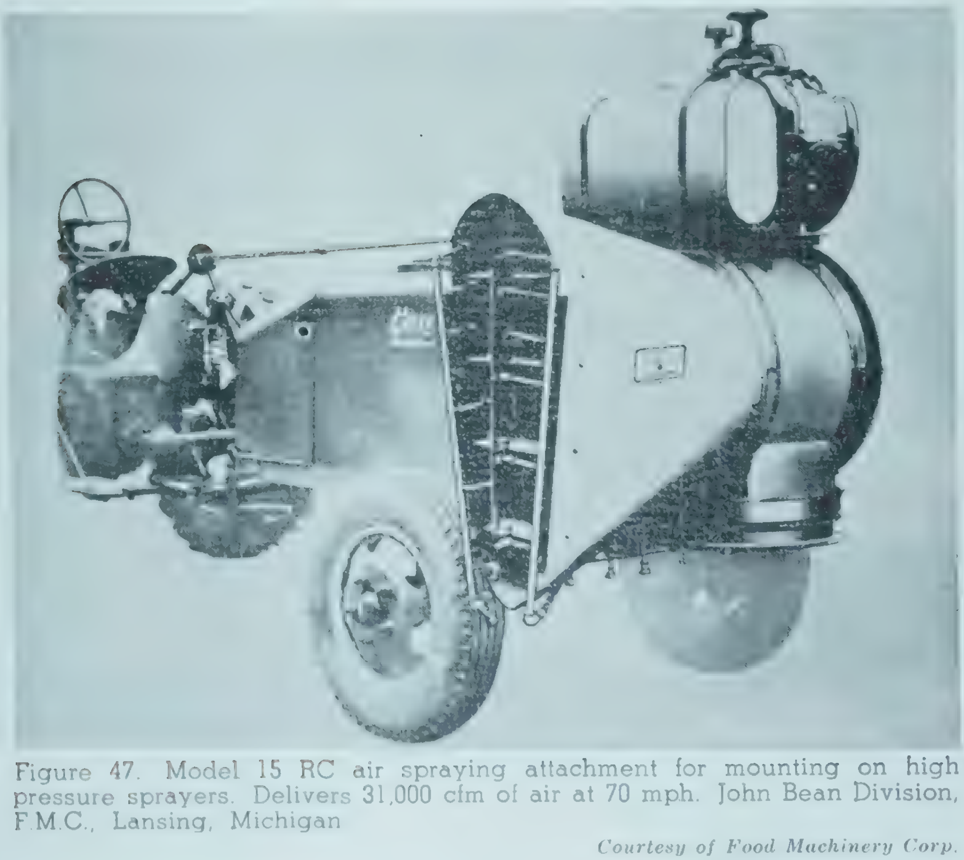


Figure 47. Model 15 RC air spraying attachment for mounting on high pressure sprayers. Delivers 31,000 cfm of air at 70 mph. John Bean Division, F.M.C., Lansing, Michigan

Courtesy of Food Machinery Corp.

other is the adjustable slot in the discharge housing. This provides easy control of velocity and volume of air discharged on plants close to the sprayer.

Specifications

Model: No. df-20-A Air Blast Row Crop Sprayer

Pump: 30 g.p.m. at 400 p.s.i.

Power Unit: Continental Model F-226, 75 hp. at 2200 r.p.m.

Blower Unit: Two, 20" Hardie Axial flow fans with supercharging action, delivering air velocity up to 90 m.p.h.

Tank: 300 Gal. Steel.

Agitator: Positive, mechanical

Fan Driver: Direct drive through torque tube

Drive to Pump: V-Belt

Controls: All controls within easy reach of tractor driver

Discharge: Gallonage may be varied by changing nozzle disc. Air speed and velocity controlled by engine throttle. Outlet can be reversed from side to side from tractor seat.

Wheels: Timken Roller Bearing with 900 x 24-ply tires.

Tread: 60 inch to 72 inch.

Ground Clearance: 12 in. to 20 in.

Overall Length: 14 ft. 6 in.

Weight: 3900 lbs.

Specifications and data quoted from printed matter supplied by Hardie Mfg. Co., Hudson, Mich.

Oliver Iron Age Row Crop Spra-Blast

A. B. Farquhar Division, The Oliver Corp., York, Pennsylvania

In the development of the Iron Age Spra-Blast Unit, the manufacturer advises that every effort was made to eliminate any tendency to spray high on one side and low on the other. This tendency is corrected by specially shaped stationary vanes in the fan housing immediately behind the fan. These direct the air outwardly from the center and into the air outlet nozzle.

Rate of spray application from low gallonage concentrate to high gallonage is determined by spray nozzle discs, swath width and speed of travel. Hardened stainless steel flat fan type discs are supplied for uniform coverage.

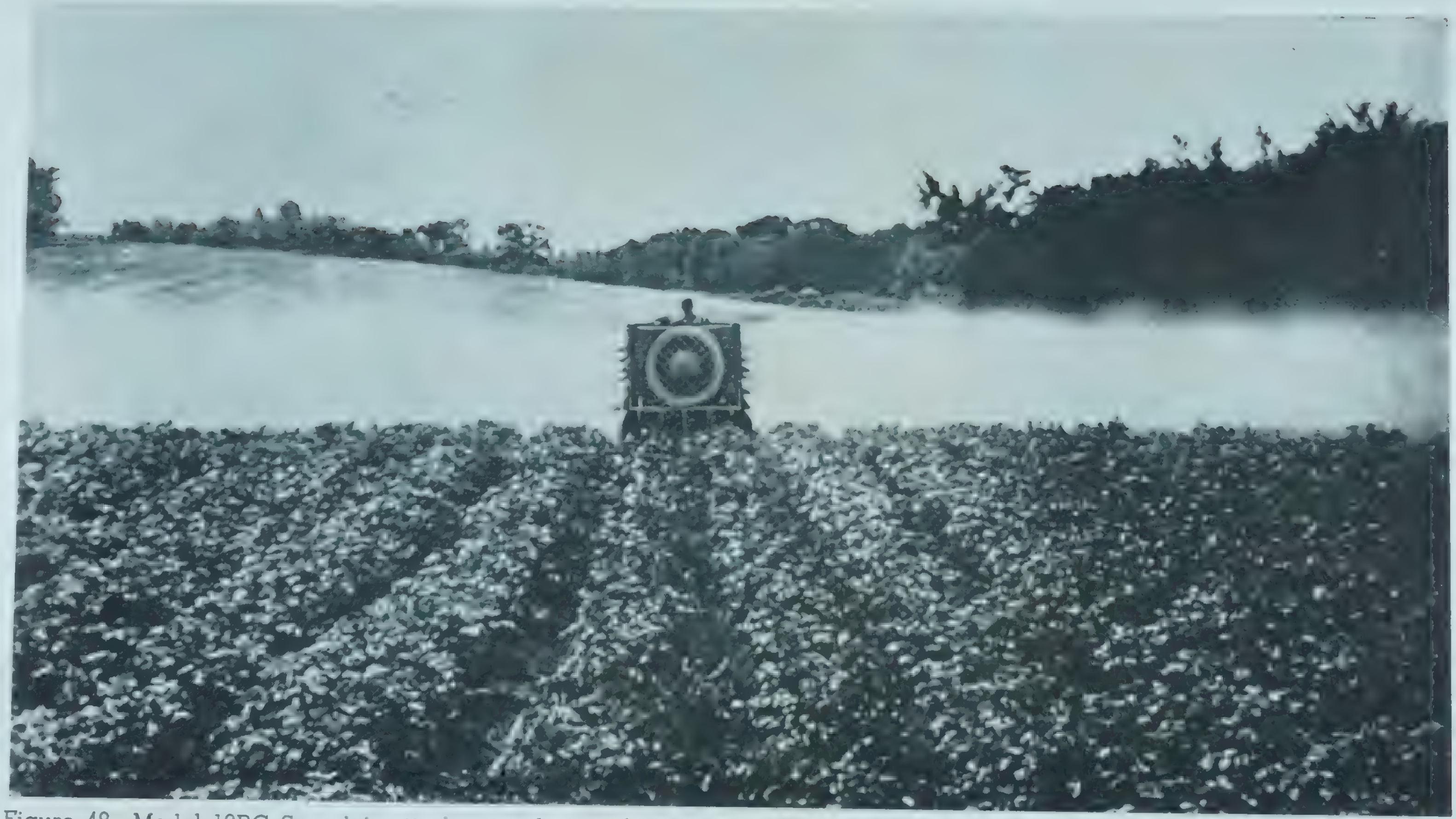


Figure 48. Model 12RC Speedair attachment, designed to convert a high pressure unit into an air type row crop sprayer. Powered by a Wisconsin VF-4 engine with 29 inch axial flow fan delivering 18,000 cfm of air at low velocity. John Bean Division, FMC, Lansing, Michigan.

Courtesy of Food Machinery Corp.

Air outlets are so shaped that the greatest volume of air comes out of the topmost portion of the nozzle and is directed to the outer edges of the swath. Movable deflector vanes are provided to allow the operator to make minor adjustments of air direction from the tractor seat.

Fan: A 29¼" diameter, eight blade fan of high strength, light weight, pressed steel construction. Balanced to eliminate vibration and equipped with rubber bushed hub to avoid wear on shaft and key.

Engine: Dependable, easy starting 25 hp. Model VF4 Wisconsin. Equipped with starter and generator.

Liquid Control Valves: Controls are located at front of tractor within reach of tractor operator. Valves provided for individual control of spray material to either side of fan. Check valves provided in the piping so that the short boom section under the unit sprays when either side is operating.

Air Direction Control: Vanes are adjusted by remote control from front of sprayer. Compensation for differences in terrain or wind conditions can be made from tractor seat.

Orchard Equipment

ACCORDING to Garman (1953), entomologist of the Connecticut Experimental Station, "Spray trends in orchards today consistently favor reduction of labor and increase in speed. With the per bushel return for fruit remaining fairly constant, the increasing cost of labor and materials has meant lower profit margins. Thus, anything that reduces labor costs is popular with the fruit grower.

One-man spray operation is becoming common, partly because owners of small orchards can do the work themselves and thus become independent of labor except for the harvesting season.

"Progress in the art of spraying has been constant since the beginning of the century. Starting with the hand pump and a nozzle or two on a pole, we have passed through the development of the gasoline pump with ever-increasing pressure, the hand gun, the multiple nozzle broom (hand operated or swivel mounted), the fixed boom, driver controlled, and finally the air blast machine with stationary or oscillating outlet, also operated from the driver's seat.

"As we progressed from low to high gallonage pumps, there has been a gradual increase in consumption of water, often taxing farm facilities. In some cases, construction of overhead tanks or small farm lakes or ponds has proved equal to the demand, but sometimes the demand is not easily met. For such conditions, the concentrate machine offers a solution to the problem because of its reduced water requirements. Much time has been spent studying mist blowers in order to determine their adequacy for the jobs to be done. Costs, spray cover, including pattern and deposit, as well as a number of other factors, are involved and have been studied."

Knowing the type of cover needed and the difficulty of placing spray throughout the tree when air was used as the transporting agency, it was at first feared that adequate pest control could not be achieved with mist blowers. There were two reasons for this: (1) in some cases, the spray deposit was not continuous, leaving gaps for entry of disease spores, and (2) in other cases, too light a deposit was obtained and not enough was placed on the undersides of the leaves to control such pests as mites, scales, and diseases. While these objections may have been justified at the time mist blowers first began to be used, they are no longer so in the light of experiment and practical experience. Failures to control have indeed been noted (Mitchell, 1949, and Burrell, 1951), but the percentage appears to be no greater than with other types of machines.

Another objection, perhaps more serious, deals with the filtering out of sprays by dense trees so that the outer leaves receive adequate to too heavy deposits, but deposits inside are inadequate. Under such conditions high volume, medium velocity air delivery is considered more satisfactory. Dense trees have little place in most orchards, however, since they tend to hold moisture within the canopy, and controls are frequently unsatisfactory even with the best hydraulic equipment. Success depends in part, therefore, on good orchard practice and not solely on the use of any particular type of machine or equipment.

Some air blast machines do not always provide enough air volume and velocity to give pest control in tall trees no matter how the trees are pruned. A few are extremely variable in air delivery from one portion of the air exit to another. Such machines should probably be used only on smaller trees, for example, peaches, or apples pruned down to suitable height. (Garman, 1953)

Concentrate spraying is especially efficient for in-the-rain applications of such protectants as the sulfurs during the early part of any scab infection.

The first air blast machine to come into orchards was the Niagara "Liqui-duster," introduced about 1930. It was followed about five years later by the "Speed" Sprayer, which used an airplane propeller to blow conventional mixtures ejected from solid stream jets. Neither of these rigs was designed for applying concentrated sprays. After the idea of using concentrates instead of dilute sprays began to unfold, the trend was toward higher concentrations, lower gallonages, smaller pumps, less pressure; higher and more uniform air velocity at the target over the entire tree; smaller tanks, lighter machines, faster rate of travel, handy spray shut-off levers, metering devices, and low speed speedometers. There is also a trend toward night application in some areas. Thus far, most orchardists are not using greater than 8 to 10x concentration. However, vast improvements can be made in application efficiency and technics, and it is conceivable that concentrations as high as 15x may be possible in 5 or 6 years. Moreover, the development of nonpoisonous systemic pesticides may effect a vast reduction in the gallonage required per tree or per acre.

This reduction has been demonstrated by use of as little as five gallons of hormone concentrate per acre of orchard in average drop size ranging from 40 to 160 microns. This also indicates that a wider range of drop sizes can be used in the case of systemic pesticides.

Another potentially great field that may permit the use of higher concentrations and larger drops is the application of foliar sprays of nutrients and fertilizers for improving tree health, growth, and fruit flavor. This is a relatively new field that needs a great deal of research.

Deposit

THE question is often asked—what kind of spray deposit is desirable? (Garman, 1951) From experience, the cover must be sufficient so that distances between the spots of spray will not be much more than 1 mm (1/25 inch) or certainly not greater than 1/16 inch. Some authors say "continuous," but spots one millimeter apart readily coalesce when rain or dew occurs. All foliage should, of course, be hit by the spray. In dry seasons, however, there is often a tendency to pile on too much pesticide. Since the mist applications do not remove any of the previous spray, excessive residues may result.

Borden (1952) gives the following data for mist blowers operating on two to 10x concentration based on the gallonage required to do the work of high pressure outfits.

Concentration	Gallons required (fraction of that used by conventional outfits)
2x	2/5
3x	3/10
4x	1/5
6x	1/8
8x	1/10
10x	1/12

In view of the non-removal of previous sprays, it is well to reduce the concentration gradually as the season advances in order to avoid excessive residues and at the same time save as much spray as possible. On the other hand, the grower changing from dilute to concentrate sprays will do well, at least in the beginning, to apply as nearly as possible the same amount of actual spray material (not diluted spray) as he is accustomed to apply with hydraulic or high pressure rigs, later reducing the amounts as he acquires experience. Rain and degree of tenacity of the chemicals are two factors concerned in the loss or build-up of deposits in addition to the number of successive applications of the same materials.

Hang-On (Attachment) Blowers

THE hang-on blower has been developed largely as a means of converting older, less efficient hydraulic sprayers to more efficient operation.

This type of blower can be attached readily to the conventional hydraulic sprayer and is controlled from the driver's seat. While it reduces the necessary man-power, there are some drawbacks to the hang-on blower. The first attachments were too light, with no shock absorbers, so that they shook themselves to pieces in a few hours or days. The second disadvantage lies in the rather low air volume and air speed so that tall (25-30 feet) trees are not easily covered. Figure 50 shows the height reached by one of the machines tested. The top bar of the screen is 27 feet from the ground. For small apple trees or peaches, the attachment blower is nevertheless a distinct improvement over older methods. (Garman, 1953)

Another feature to be considered is the extra engine required and the additional gasoline and servicing. In spite of these disadvantages, a few of these machines operated successfully during 1952.

Day Versus Night Spraying

THE advantages of night over daytime operation of mist blowers are obvious, at least to growers who have used the method, and in 1952 there was a trend towards night spraying. Whether improvement in performance of mist blowers will reverse this trend remains to be seen. Advantages of night over daytime operation are (1) Ability to see where the spray is going; it is difficult to observe concentrates in daylight. (2) Air currents are frequently down at night instead of up as they are during the day, so that small drops settle readily. (3) Evaporation rates are less, giving small drops a chance to settle without further concentration. (4) Temperatures are cool and wind currents are usually less, adding to the comfort and safety of the operator, except when very poisonous materials, which may hang in the orchard, are used.

Outlets for Fruit Tree Spraying

IN general, outlets for fruit orchards are intended to (1) permit operation of the spray machine by one man, (2) provide efficient coverage over the entire tree, at the highest rate of travel, (3) be adjustable and adaptable for trees of different spacings, sizes, and heights, (4) waste the least amount of spray material, and (5) permit the use of nozzle systems designed to give the atomization desired and the highest effective concentration of toxicant in the mixture.

Several general types of outlets have been developed, including: (1) single round, (2) fan or fishtail, with and without louvres, partitions, fins, or vanes, (3) multiple round, (4) slot types, and (5) combinations of the above.

Various types are shown in Figures 51 to 55, see Figure 38 also.

The single and multiple round outlets are usually operated with a single nozzle in the center of the outlet. The single, round outlet machines require two men for operation since one man is needed to handle the flexible outlet while the other one drives. They are smaller and lighter than most fixed outlet types and are advantageous on

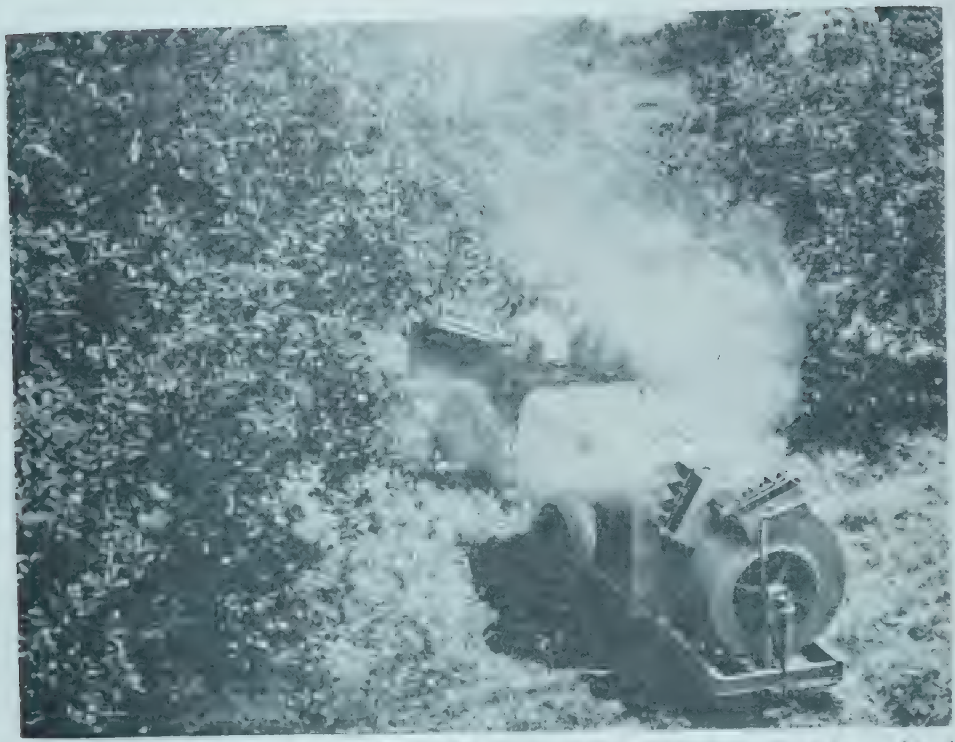


Figure 49. F. E. Myers Silver Cloud Concentrate Sprayer in an apple orchard.

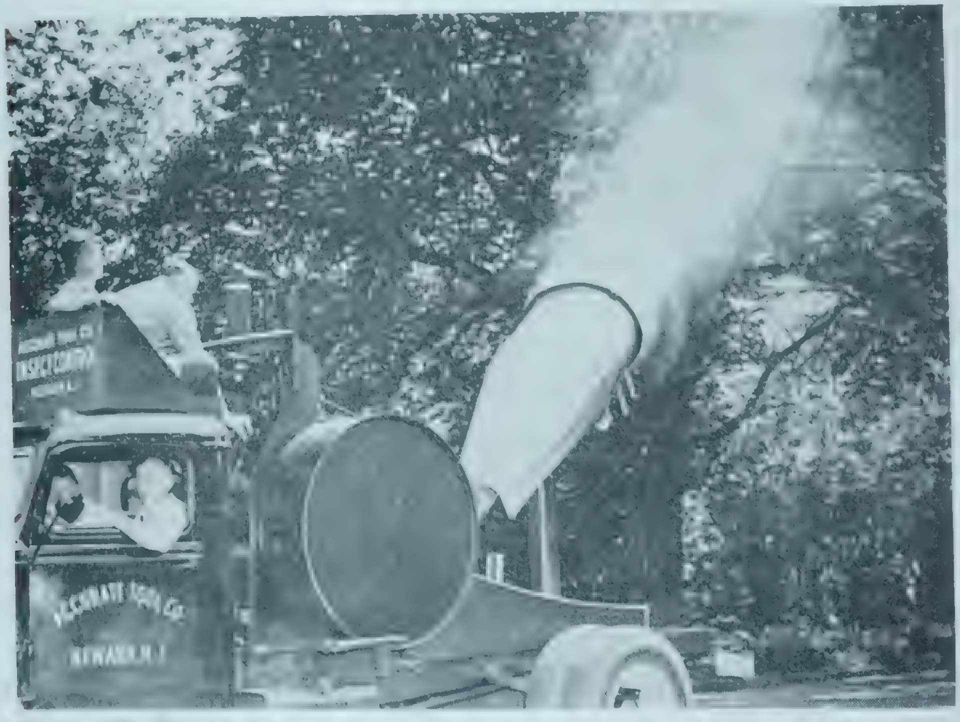

INSECT CONTROL
NEWARK, N.J.

Figure 50. Spray emerging from blower showing height reached by spray.

ground that is too soft for heavier machines; for trees on the edges of orchards and hills that are difficult to reach; and for orchards of medium small to small area. These single outlet units will reach the tops of fruit trees of any height if the air velocity is greater than 120 m.p.h. and the outlet greater than five inches in diameer. When treating large trees, the rate of travel is 0 to 1.5 m.p.h., averaging 0.75 m.p.h.

High powered machines with outlets of 12 to 24 inches in diameter have not been successful in orchards because of the difficulty of spreading the air close to the sprayer and because the concentrated air blast sometimes knocks off large fruit.

Nine inches is the largest diameter outlet that has been used successfully, as developed by the Department of Plant Pathology at Cornell University. The outlet is operated from the rear platform of the machine by a lever which points the outlet to any direction since it turns on a swivel. (Brown, 1948) The air stream is directed to the rear of the machine in order to give it a chance to spread and diminish in velocity before reaching the trees. A highly skillful, experienced nozzle-man can obtain as good results as for the fixed outlet rigs, and often uses less total toxicant at a higher concentration and lower volumes per tree. In fact, the round outlet is capable of giving better penetration through dense foliage. However, a poor or mediocre operator may obtain poorer results than for the fixed outlet machines.

Multiple round outlets are shown in Figures 51 to 54. One conventional liquid whirljet (B1, B2 or B3) or Monarch nozzle is reversed against the air blast in each outlet opening (Figures 51 to 53). The included angle of the round outlet manifolds ranges from 50 to 100 degrees for 3, 4, 5, 6 and 7 hole outlets. In the triple outlet (Figure 53) the angle of spread can be set between 0 and 70 degrees by turning it from the horizontal towards the vertical position.

The stationary triple and quadruple outlets may not cover sufficiently the tops of 30-foot apple trees. When the outlet manifold is oscillated up and down by means of a cam eccentric, coverage is effective. When oscillated, the triple outlet is slightly more effective in a horizontal position than when in a vertical position.

J. L. Brann (1953) of Cornell University has devised a means of rotating these multiple round outlets by power from the motor at 10 to 20 r.p.m., as well as a mechanism for discharging a greater

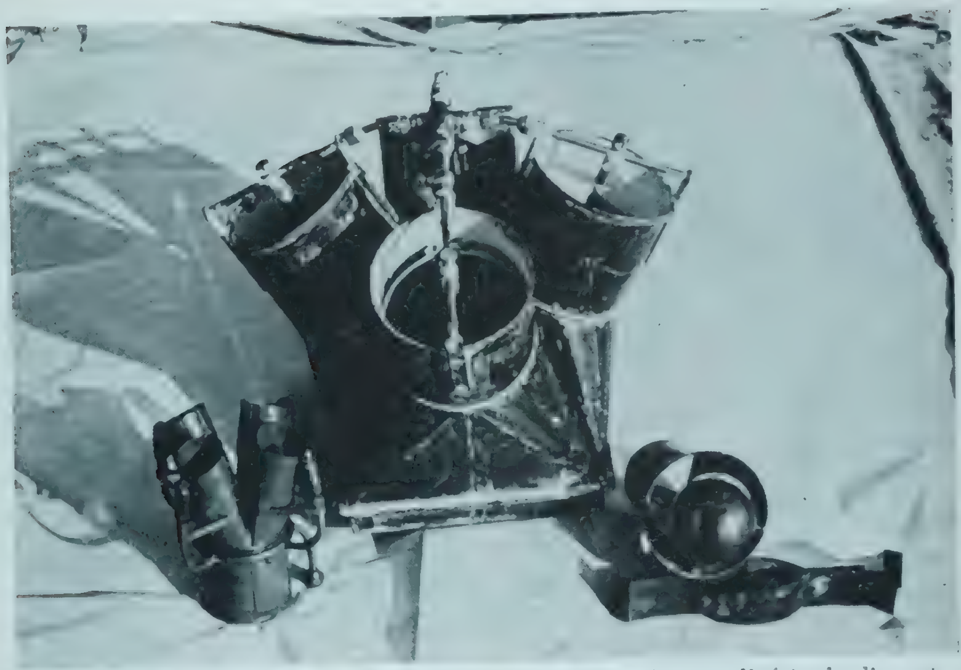


Figure 51. Quadruple spreader outlets. Assembly for small 4-inch diameter outlet is at lower left. At upper center is a large outlet for fitting onto the 14 x 14-inch outlet of a 25 hp machine. A liquid nozzle is reversed against the air blast in each of the four outlets which are each $7^1/_4$ inches in diameter.

Potts, Garman, Friend, and Spencer, 1950.

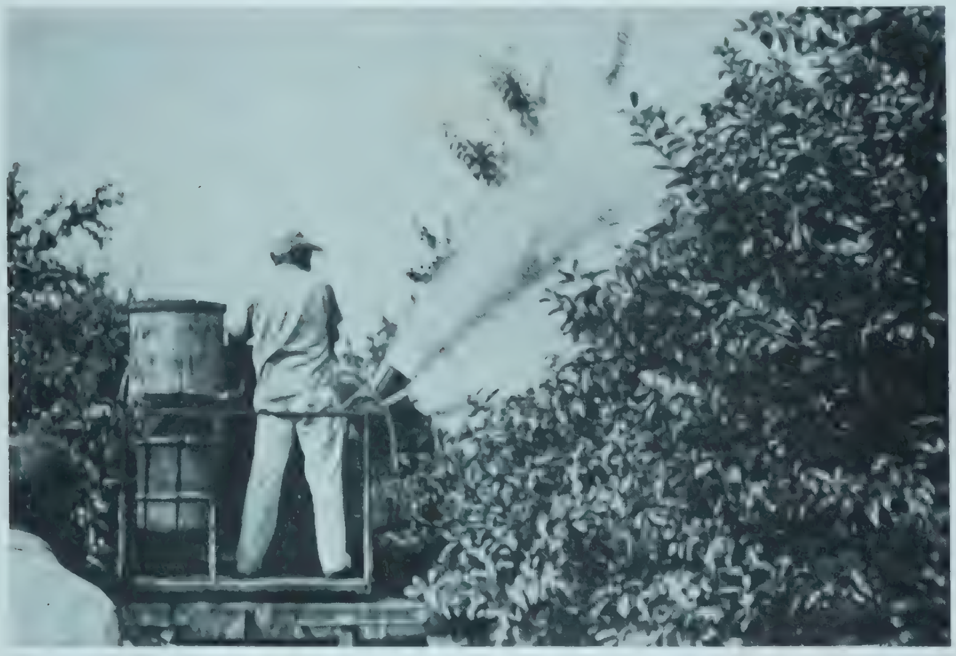


Figure 52. Quadruple spreader outlet with 50 degrees included angle.

Potts, Garman, Friend, and Spencer, 1950.

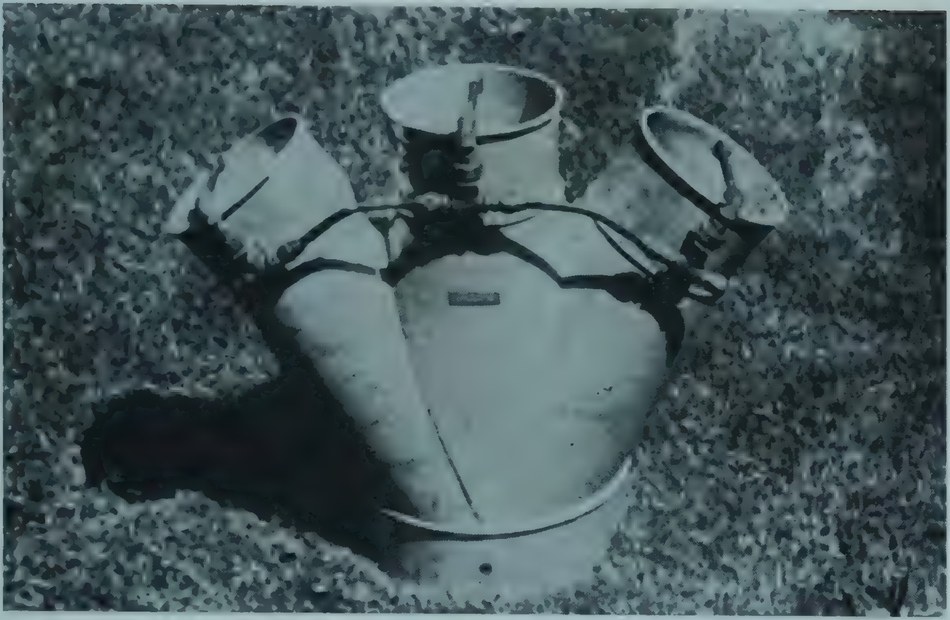


Figure 53. Triple outlet manifold with outlets forming a 70 degree included angle. The outlets are each 7 inches in diameter and have a No. 2 or No. 3 whirljet nozzle reversed against the air blast at the center of each outlet.
Potts, Garman, Friend, and Spencer, 1950.

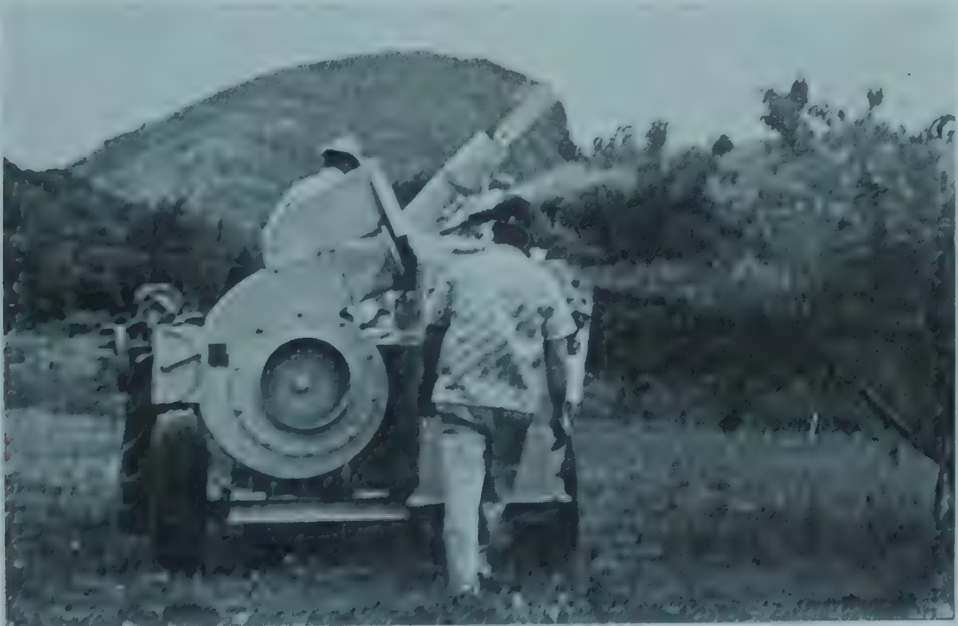


Figure 54. Rotating triple outlet developed by J. L. Brann.
Courtesy, J. L. Brann

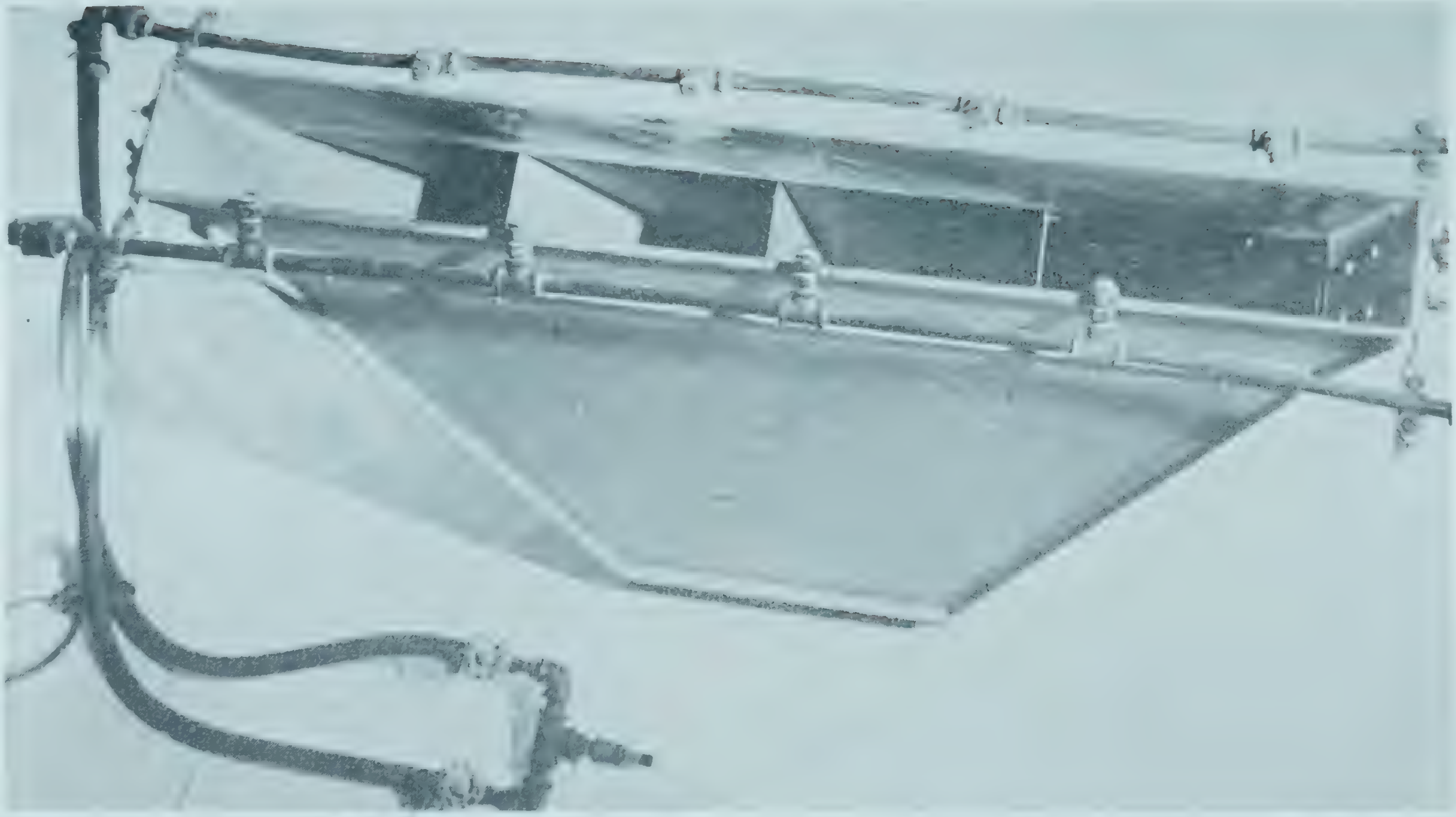


Figure 55. Fan-shaped outlet, 4 x 36 inches, with spreader vanes and nozzle assembly of eight staggered fan spray nozzles directed at a 35 degree angle against the air blast. Two shut-off valves and plugs enable the operator to use from one to eight nozzles.

Potts, Garman, Friend, and Spencer, 1950.

quantity of spray mixture through each outlet's orifice while it is pointing towards the tree tops (Figure 54).

The ordinary, single fishtail type outlets without spreader vanes have been unsatisfactory for big trees in that (1) their outlets are too narrow (1 to 3.5 inches) to obtain distance and penetration when traveling more than 1.5 miles per hour, (2) they do not provide sufficient angle of air spread, and (3) the highest velocity is in the center of the outlet.

Figure 55 shows an outlet, 4 x 36 inches, with spreader vanes, and four nozzles on each side. The nozzles are staggered so that no two are opposite each other. Moreover, there is a shut-off valve for each side so that, if desired, the nozzles of one side can be shut off while the others are spraying. Usually the nozzles are reversed against the air blast in the mouth of the outlet.

One problem with fishtail outlets is the fact that many big orchard trees require a spray-stream spread of as much as 120 degrees. A theoretical spread of 90 degrees is not sufficient to cover the entire tree. To improve coverage a triple fishtail outlet was designed to give a 180 degree angle of spread (Figure 38).

An effective slot-type outlet, 3.5 inches wide x 7 feet long, has been developed (Figure 56) by Cornell University pathologists and engineers (Pratt, 1948) and is now in commercial production by the Hardie Mfg. Co. It is not a true fishtail type. This outlet is provided with movable vanes for directing the spray. It gives excellent coverage as compared to most other machines, particularly on the undersides of the leaves. If there is a weak spot, it is at the top center of tree crowns. The outlet sits at an angle of 35 degrees with the ground. Fan-type, Teejet nozzles, with 16 to 20 mesh screens are placed outside the air slot. Hence, atomization is not as fine as for some other types. Usually 200 to 600 p.s.i. pump pressure is utilized to help break up the spray, since the air velocity is limited to about 115 m.p.h. The machine is well adapted for big orchards, but is not as well suited for small trees, and close low plantings.

Another type of modified slot outlet is the circular or arc type such as used on the "Speed Sprayer," and which may spray to one or both sides of the machine. It should deliver heaviest spray volume at "ten and two o'clock," either by using more nozzles or nozzles with larger openings (Figure 58), and should be provided with an adjustable volue to drive the spray across the tree tops. Otherwise,

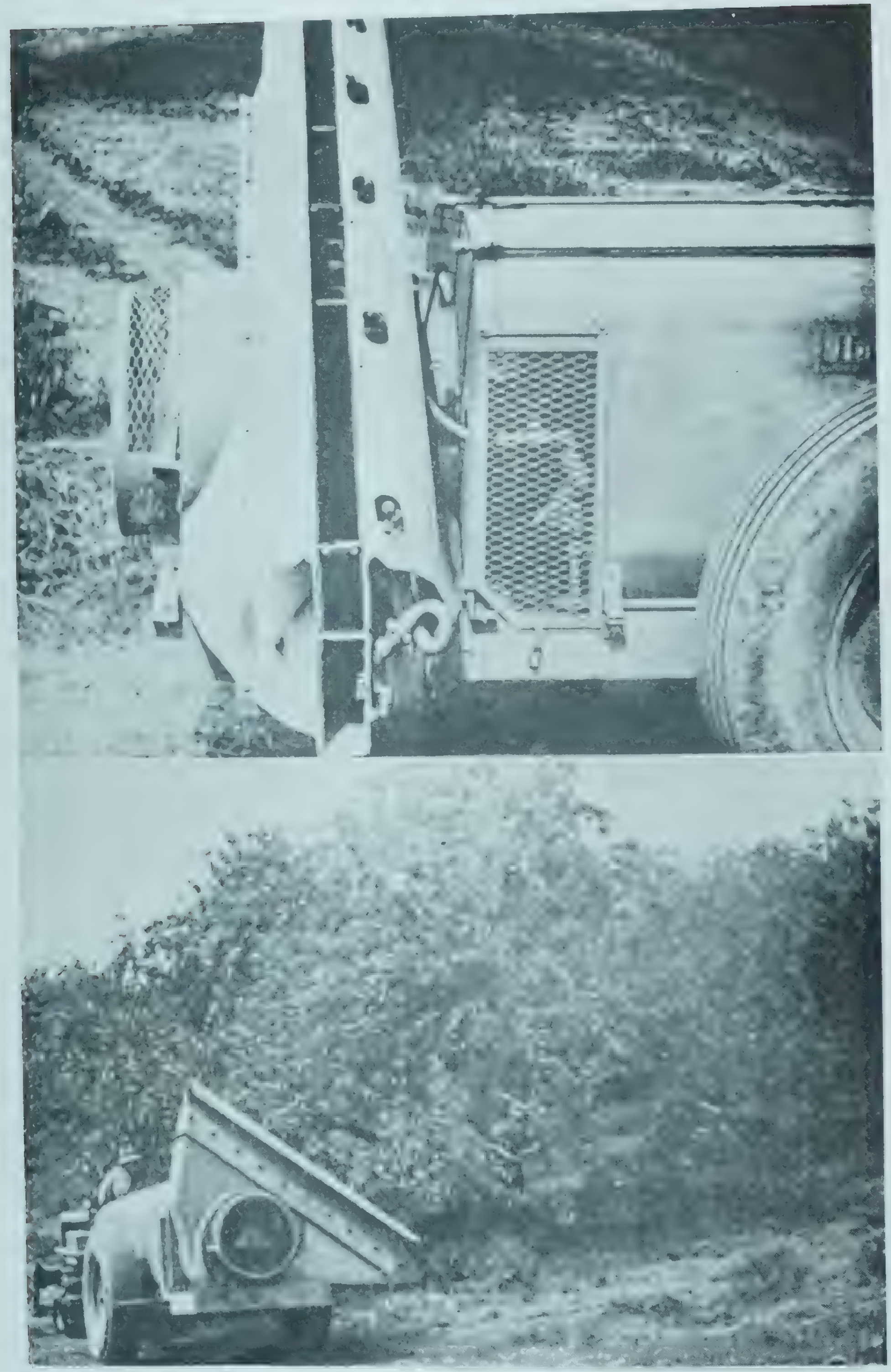


Figure 56. The Hardie "Orchard Mist" provided with T-jets and movable vanes in slot for directing spray. This machine is designed for concentrates.
Courtesy, R. M. Pratt, Cornell University.

a big portion of the spray would be lost by being thrown up into the air directly above the machine.

The Speed Sprayer type of machine is being made by several companies with numerous variations. It has a popular appeal for growers, due in part to its streamlined appearance. The first models did not have enough air velocity (75 to 110 m.p.h.) nor the nozzle arrangement and design for extremely low gallonages and high concentrations. Too often the tendency has been to sacrifice velocity for volume. However, some of the newer models deliver more in velocity than the older ones. They can also be made to deliver more air and spray from the upper portion of the outlet than from the lower portion. This type of slotted arc outlet has been fairly successful even though it does not give the most efficient use of air.

A modified V-shaped slot is sometimes employed as a means of throwing more air and spray to the tree tops. Nozzles that discharge the greatest volume of spray are placed at the top or wider portion of the V (Figure 58).

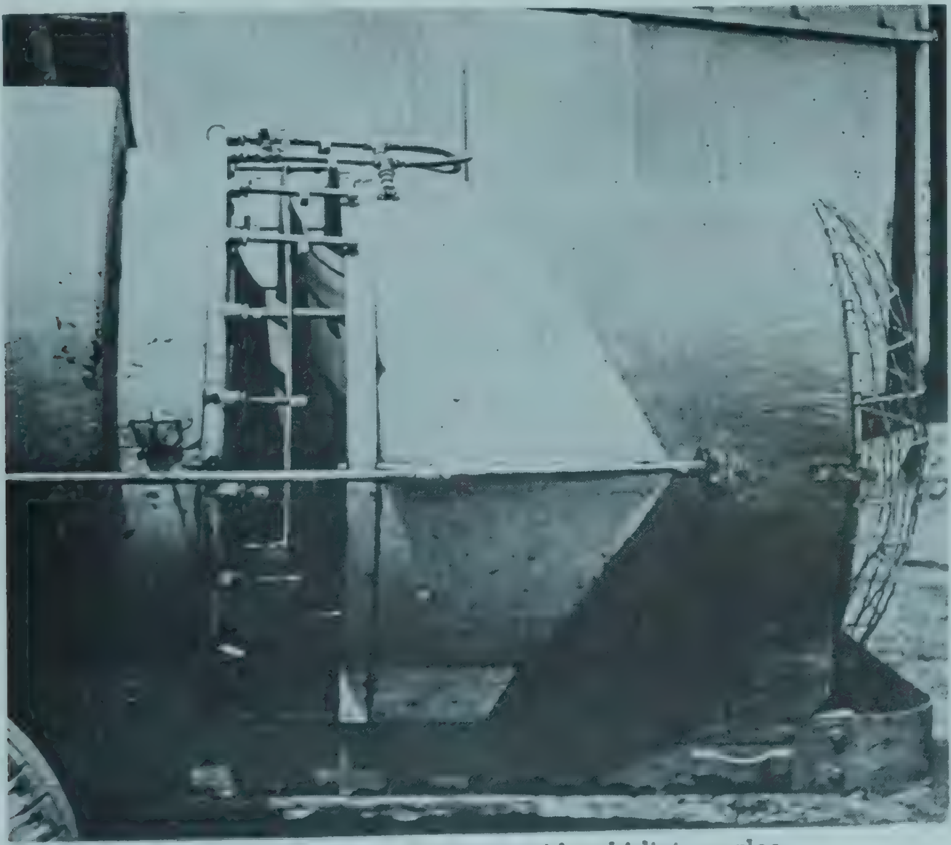


Figure 57. Speed Sprayer with whirljet nozzles.

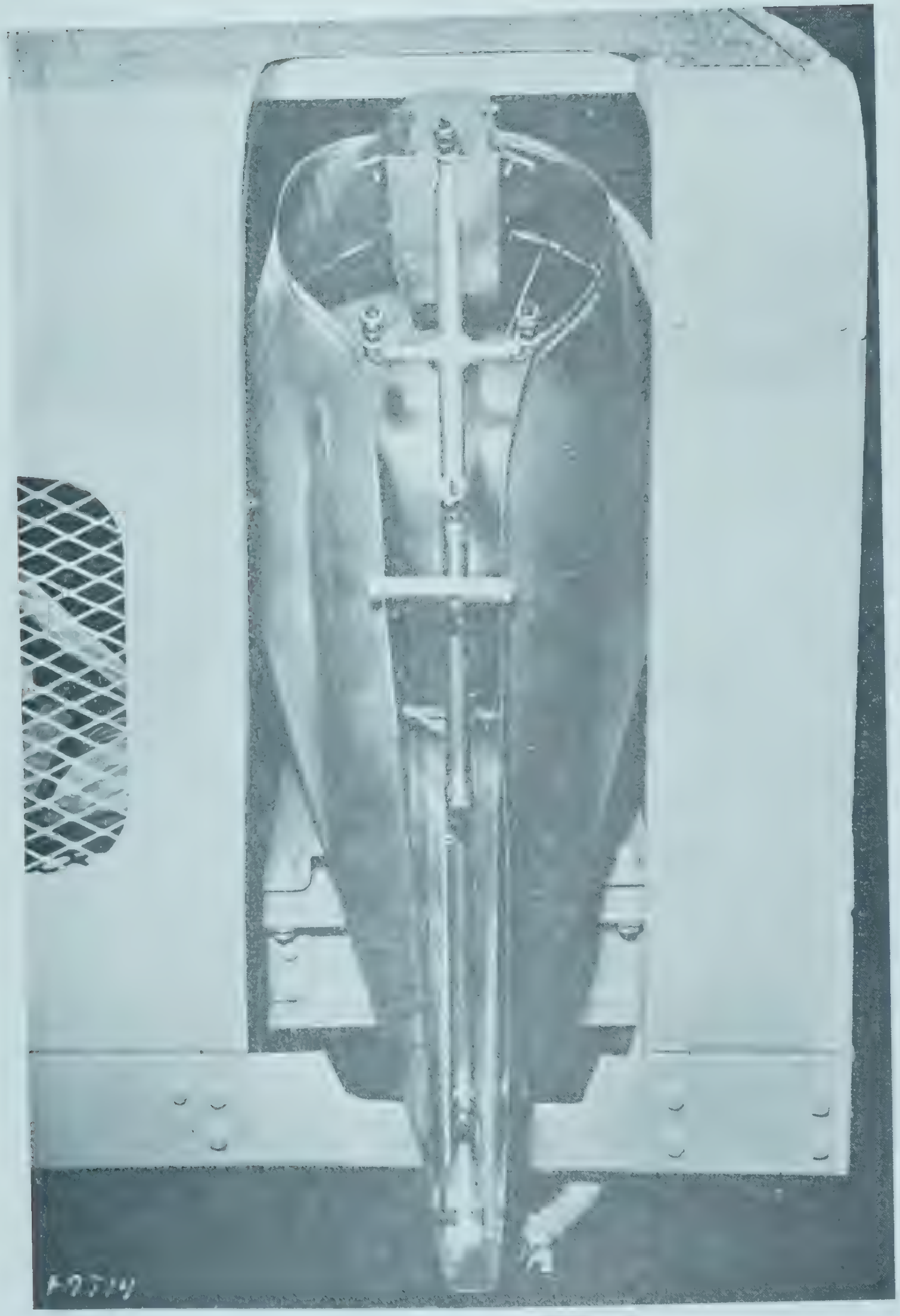


Figure 58. Iron Age orchard machine designed to deliver more air and **spray** to the upper part of the tree than to the lower portion of the tree.

Courtesy, Oliver Corp.

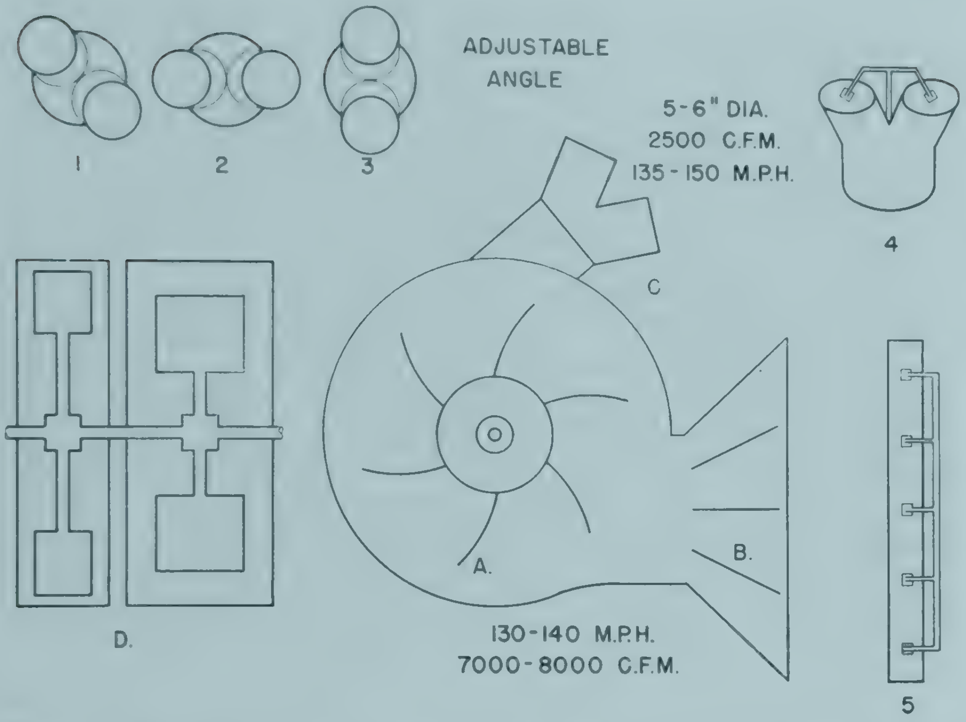


Figure 59. Adjustable, dual -orchard type outlet. **A.** Curve bladed fan to deliver 7,000 to 8,000 cfm of air at 130-140 mph. **B.** Vanes for directing the air **C.** Double, 6-inch diameter round outlets from fan delivering air at 135-150 mph. Outlet is adjustable for both height and angle of spread, as indicated in 1, 2, and 3. No. 4 shows position of nozzles. **D.** Shows both fans on the same shaft.

Design of Special Type Outlet

THE ideal machine should make the greatest use of power and air so as to permit high insecticide concentration, low gallonages, fine atomization, sufficient velocity at the target to give required deposit and coverage, reduce waste and weight, and make possible the maximum rate of travel of the sprayer. An outlet that is ideal and adaptable in all respects has not yet been developed. However, a great deal of study has indicated certain structural designs for increasing efficiency. One such design, requiring 35 to 40 h.p. for operation, is shown in Figure 59. In it two outlets, adjustable for tree size and height, house two fans driven on the same shaft. The large spreader outlet (about 4 x 30 inches with spreader vanes) covers the lower 12 to 18 feet from the ground with air at 130 to 140 m.p.h. from a low position on the machine, while the double round outlet directs the air-spray stream to the tree tops from a position at the top of the machine, Figure 59. Both outlets can be adjusted up or down on the fan shaft for changes in tree height.

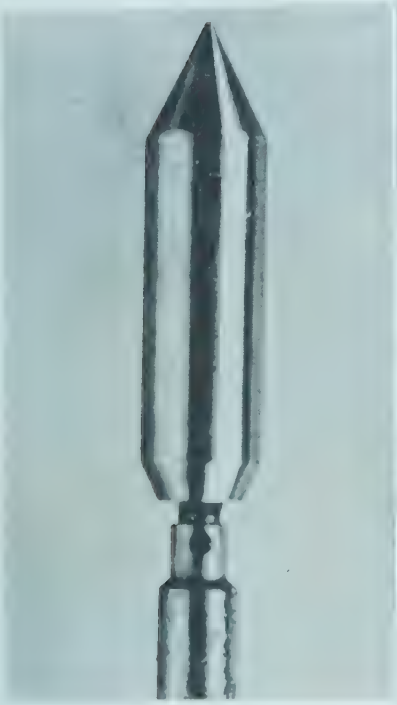


Figure 60. The Brann nozzle used in one make of mist blowers.

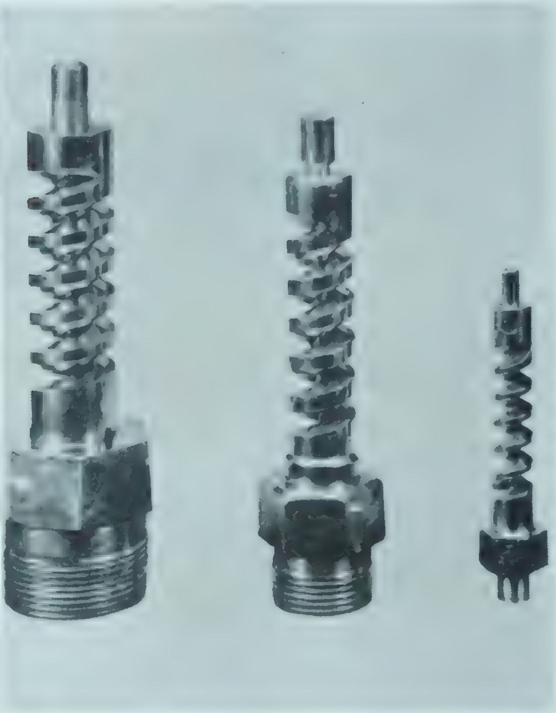


Figure 61. Spiral nozles. Atomization is produced outside of the nozzle to reduce clogging

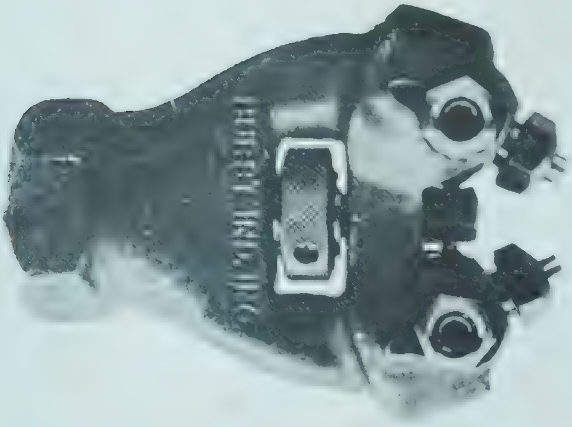


Figure 62. Aqua-jet nozzle giving break-up by collision of two solid stream jets of liquid meeting at high pressure.

Courtesy, Cardox Corp.

Nozzle Systems for Fruit

IN early studies of mist blowers, it soon became apparent that available nozzles were not suitable for concentrated orchard pesticides. The main difficulty was that clogging resulted when the concentration was increased to permit reducing the gallonage of spray suspensions. As a result, provisions were made for overcoming this difficulty by a combination of approaches, beginning with the invention of a suck-back mechanism which returns all the spray mixture to the tank whenever the lines are shut off. Other schemes include the use of a set of suitable strainers between tank and pump and another strainer just back of the nozzles. The strainers should be cleaned from time to time, the tank should be flushed at the close of spraying operations, and mixtures kept free of trash and corrosive flakes from the surface of the tank. At the end of the season the tank should be coated with a protective material that will not flake off or permit rusting.

A great deal can be done to prevent clogging by selecting the right nozzle and by using as few nozzle orifices as possible so that large orifices can be used.

In installing nozzle systems on mist blowers a number of items must be considered. The nozzles must be placed where they will give the greatest degree of atomization and fill the air stream, in-so-far-as-possible, with the fewest number of nozzles and without the spray striking the sides of the outlet. This often calls for pointing the nozzles against the air blast or at right angles to it. Among the nozzles that give a minimum of clogging are the Brann nozzle, parasol nozzle, spiral nozzle, and Whirljet nozzle (Figures 60 and 61).

The Brann nozzle depends on air velocity for atomization.

The "Aqua-jet" nozzle is a non-clog type but requires high pressure (400 to 800 pounds) and two big orifices to each nozzle for atomization (Figure 62). Therefore, it is difficult to use this nozzle for low gallonage concentrates unless the number of nozzles can be drastically reduced. The parasol nozzle has a ¼-inch opening at the tip which gives a wide angle of spread (160-180 degrees). The liquid output is governed by an intake port hole in the whorl chamber. Like the Whirljet nozzle, it has no whorl grooves. The Teejet and other fan type nozzles are often used on the long, narrow fishtail or slot type outlets. They tend to clog more often than the cone type nozzles which utilize a larger orifice to deliver the same amount of spray. Shear types have not been very satisfactory.

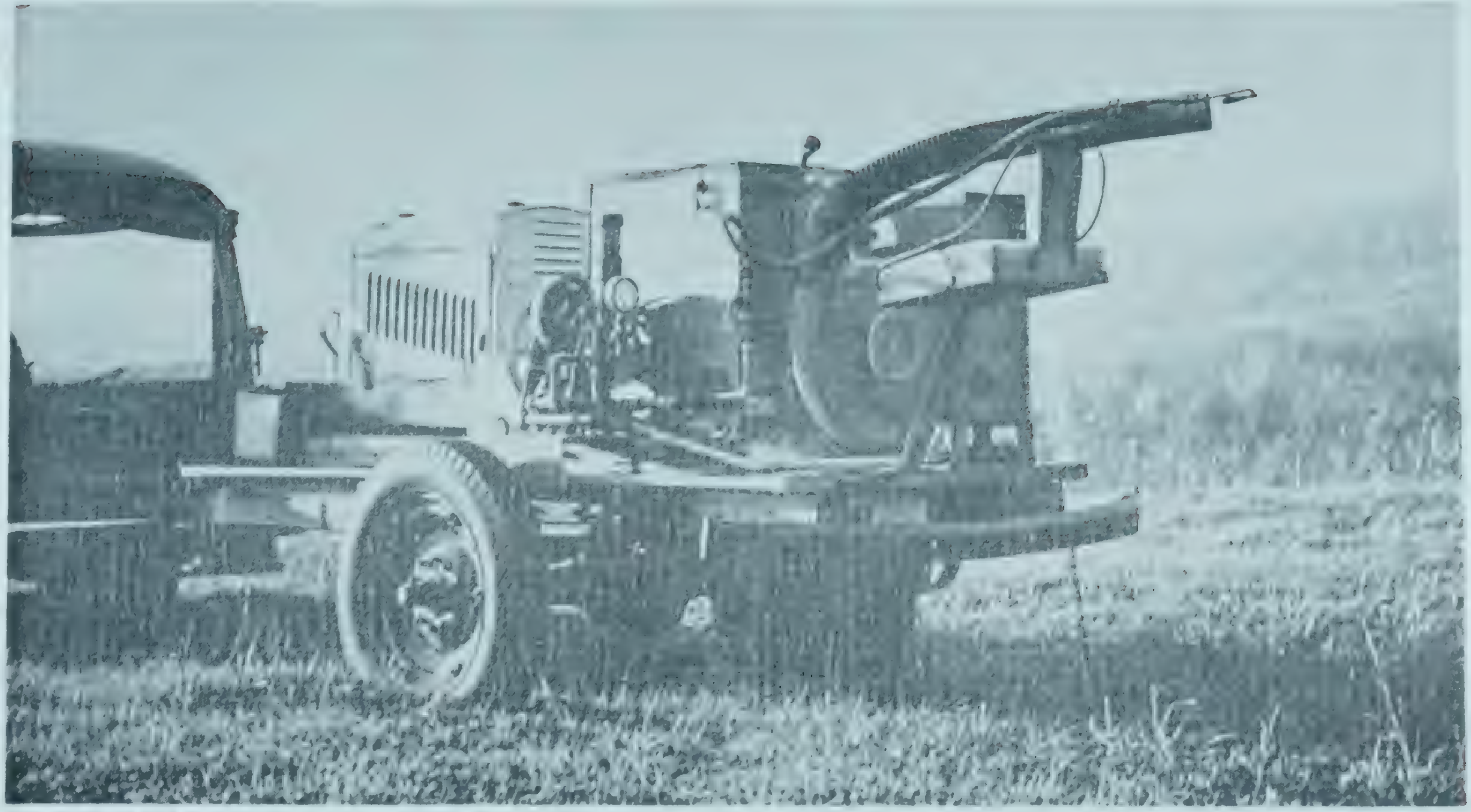


Figure 63 Cyclone duster converted to a concentrate sprayer and sprayer-duster. Mounted on a two-wheel trailer with spring seat and with a nozzle reversed against the air blast in front of outlet

Petts, Garman, Friend, and Spencer, 1950.

The number of gallons of mixture to be applied per minute determines the number of nozzles, their orifice size, and the pressure. The number of gallons required per minute is determined directly by the tree spacing and rate of travel of the machine. For example, at 30 gallons per acre a machine treating 40 foot rows from one side at 2 m.p.h. travel would apply one gallon per tree, cover 4.8 acres per hour, and deliver 2.42 gallons of spray per minute. To deliver the 2.42 g.p.m. at 50 p.s.i. would require six No. 2 Whirljet nozzles or the equivalent. If the machine traveled 3 m.p.h., nine No. 2 Whirljets would be needed at the same pressure; six such nozzles at 100 p.s.i.; or six No. 3 Whirljets. (See Tables 50 and 51).

Adaptations of Existing Equipment

MANY growers have orchard dusters of the type which can be converted for concentrate application. One model delivers about 1,300 c.f.m. of air at 175 m.p.h. through a 4-inch diameter outlet (Figure 63). The high air velocity provides a good break-up of spray.

A converted machine is shown in Figure 63. It consists of a 30-gallon tank with mechanical agitator to turn at 100 r.p.m.; a 2 to 5 gallons per minute (2 g.p.m. is sufficient) plunger pump; one line strainer of 16-mesh between pump and lever operated shut-off valve. A 20-mesh monel metal strainer should be placed just back of the nozzle. A nozzle with orifice of 1/16 or 3/32 inch (as Whirljets ⅛ B1, B2, or B3) is reversed against the air blast near the mouth of the air discharge pipe. The unit has also been conveyed in a ½-ton covered truck. This converted machine has been used as a duster, a concentrate applicator, and for combination spray dust applications. (Potts, Garman, Friend, and Spencer, 1950, pp 25-27).

CONVERSION OF OLD SPEED SPRAYER MODELS. To make this conversion, remove all speed sprayer nozzles and the several short feed pipes to which they are attached. Replace this assembly with four to ten ¼- or ⅜-inch threaded short feed pipes, on each side of the machine. Screw one end of the pipes into a reducer bushing of the spray head manifold. Onto the other end screw a hardened steel or Whirljet nozzle, a B1, B2, or B3, depending on whether a solution or a suspension is to be applied. The number of nozzles and their vertical spacing should provide maximum deposit and coverage of the entire tree with special reference to the top center of its crown

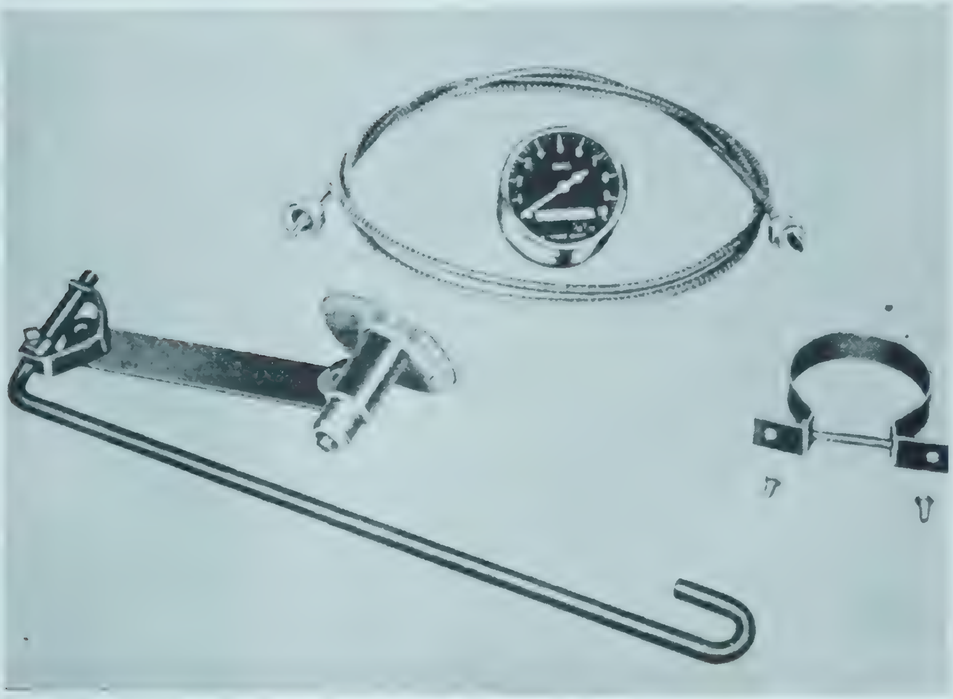


Figure 64. Parts for a typical tractor speedometer assembly.

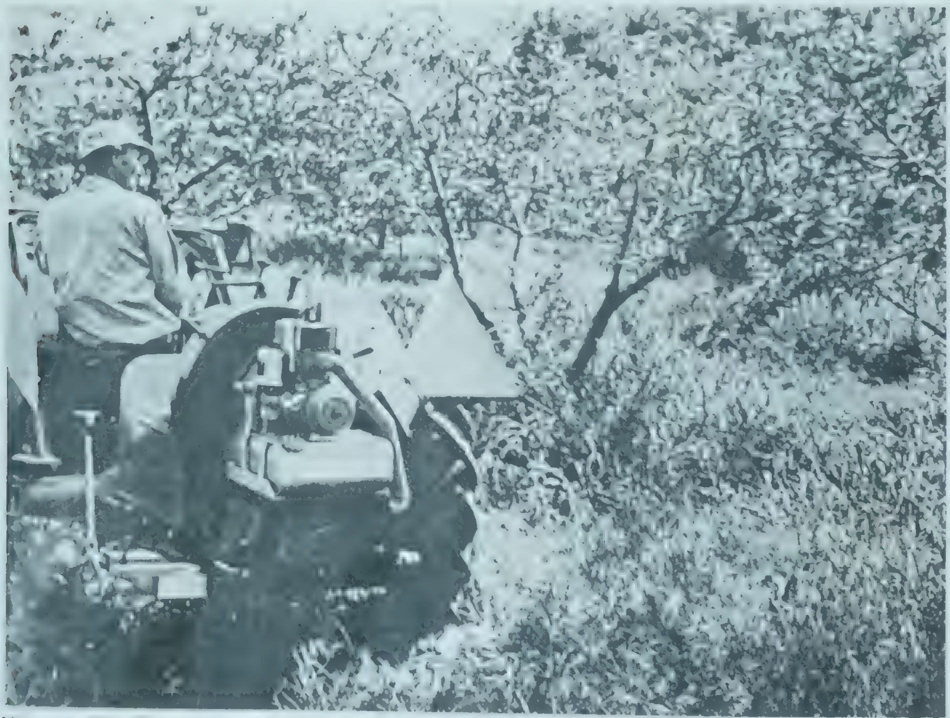


Figure 65. Treating peach trees with the machine mounted 2 feet above the ground so that the fishtail outlet can deliver spray from a low position.
Potts, Spencer, and Friend, 1953.

Four to six nozzles should be used on each side for peach trees or small apple trees; seven to ten or more for large apple trees.

The nozzle orifice is usually turned against the airblast at the point of highest velocity. This is ¼ inch back of the bell-shaped divide or baffle in the outlet, on the end towards the fan. However, in order to fill the air stream adequately we have found it desirable to place nozzles ahead of the baffle and to put more nozzles at the top of the machine than along its sides. None of the nozzle assemblies tried so far has worked well above eight times normal concentration, possibly because of low pump pressure.

A slight increase in velocity (the speed sprayer delivers 100-110 m.p.h.) may be achieved by operating only one side and closing the opposite, or by partly closing the shutters on both sides.

The B1 Whirljet nozzles are efficient for oil emulsions, miscible oils, lime-sulfur, Puratized and other solutions, but may clog with suspensions.

Helpful Operations Information for Orchardists

VISUAL estimates of coverage efficiency can be made by spraying wettable sulfur, hydrated lime, or lead oxide and checking the deposit on bark, leaves, or glass slides with the aid of a hand lens after the spray has dried. Another method is to observe the spray stream at night with spot lights. Also, fluorescent dyes may be added to the mixture as a visual aid.

In general, if the machine is delivering 20,000 c.f.m. of air at 100 m.p.h. it is possible to apply the dormant, pre-bloom, and petal fall sprays on trees of moderate size at three miles per hour travel. When foliage is fully developed, the travel rate should be reduced to two miles per hour.

It is important to check sprayer speeds frequently. This can be done by speedometer (Figure 64) or by recording with a watch the number of seconds required to travel a given distance (88 feet per minute equals one mile per hour), or the time in seconds required to go from tree center to tree center. Hence, the rate of travel, the number of minutes per row, and the quantity of spray mixture per tree or per acre can be calculated. It is also helpful to have a meter or other device for recording the number of hours the sprayer engine has run.

Tables 50 and 51 (page 191 and 198, respectively) are intended to provide treatment data for use by the orchardist.

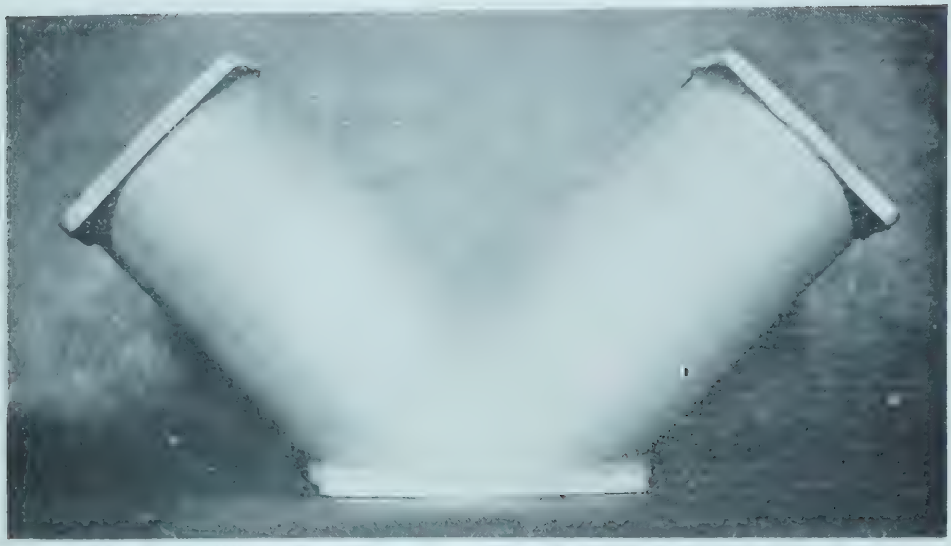


Figure 66. A double round outlet for treating one side of each of two rows of grapes with the machine travelling between the two rows. Two fish-tail outlets can be attached to the two round outlets to increase spread of spray stream close to the outlet. Potts, Spencer, and Friend, 1953.

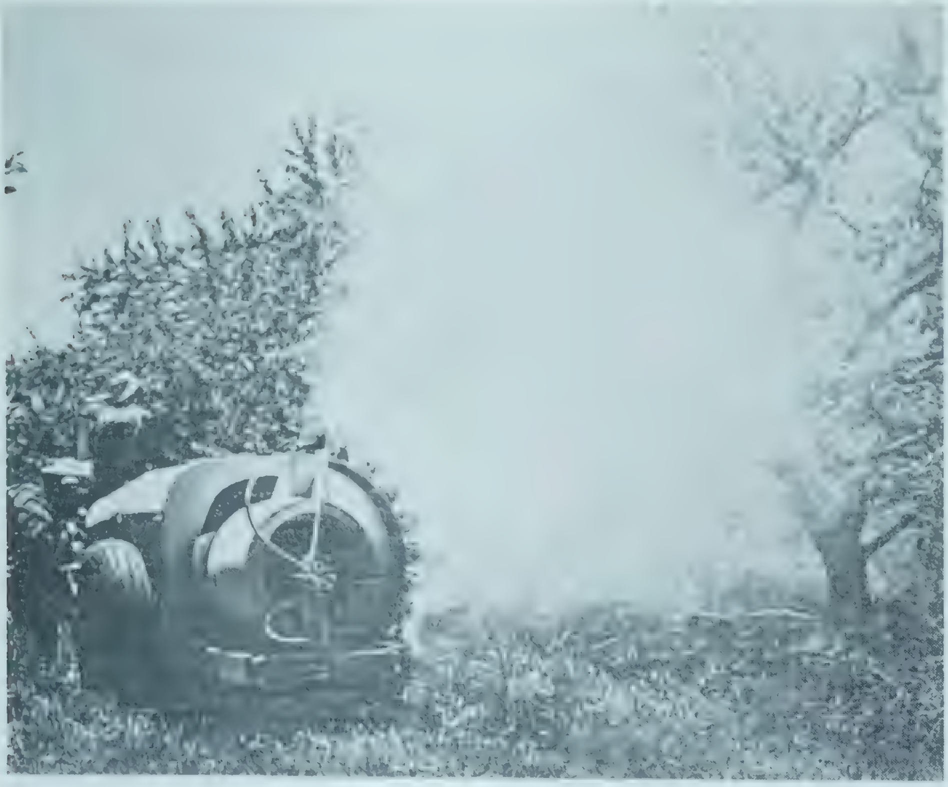


Figure 67. Myers Orchard Concentrate Sprayer with 75 hp engine, 13 gph high pressure pump, and air delivery of 26,000 cfm at 90 mph. Has adjustable outlet rotation and volute. *Courtesy, F. E. Myers and Bros., Ashland, Ohio.*

Table 50, below, indicates the number of trees passed at different driving speeds. The spray output needed per minute is found by multiplying the volume of mixture to be applied per tree times the number of trees passed per minute when the machine delivers to both sides. If the spray machine delivers to one side, divide this product by 2.

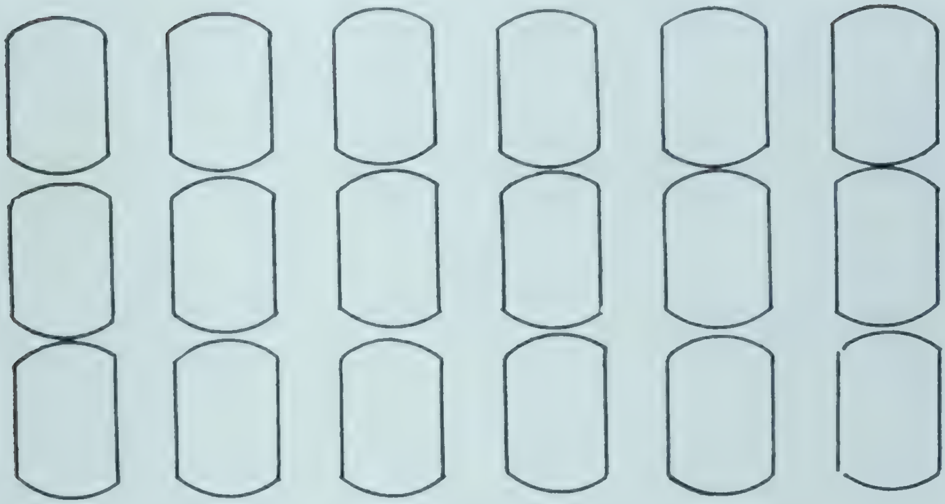
Mist Blowers in Citrus Groves

UNTIL about five years ago it was difficult to get a machine through some of the older Florida groves. Since then the practice of hedging has become widespread, thus enabling a reasonably compact machine to get through most groves as well as permitting better coverage.

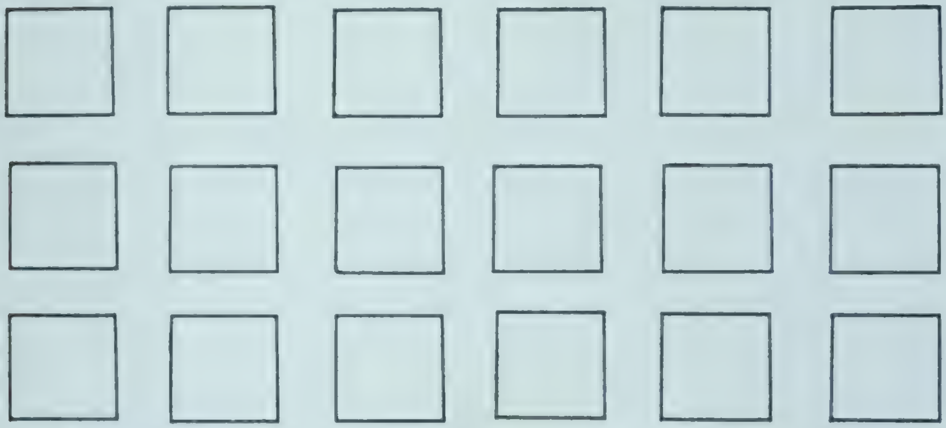
The Cornell type mist sprayer was introduced in 1949 by Dr. R. M. Pratt and the Florida Citrus Experiment Station at Lake Alfred. This machine and the speed sprayer type designs are the ones now in use. Usually a volute with movable vanes is used to improve top coverage. Unfortunately, the northern built machines are for big, widely spaced apple trees. Growers using concentrates report rather uniformly that they save 45 percent on the cost of application and 25 percent on materials. Most growers use the 6x-⅛ formula developed by Cornell. In this formula the concentration is 6 times that for the full dilution sprays, but only ⅛ as much spray volume is applied per tree or per acre as compared to the dilute spray formula.

Table 50. Number of trees passed at different driving speeds.

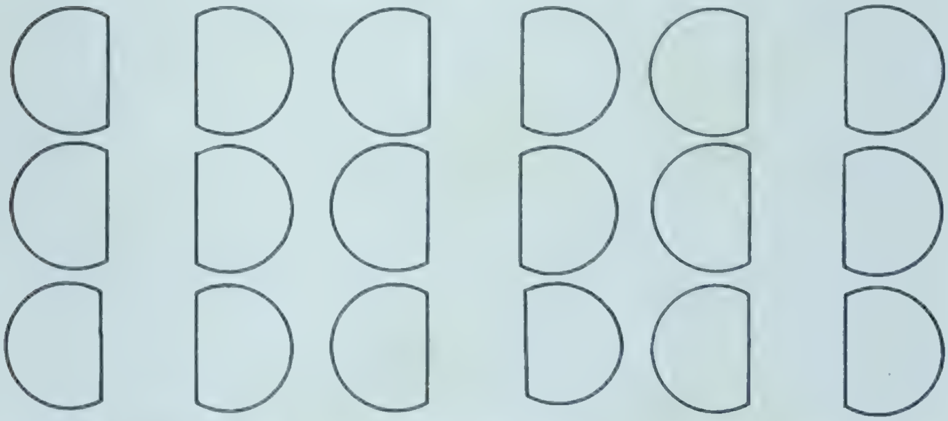
Speed of tractor		Different spacings (feet)							
m.p.h.	Feet per minute	20	25	30	33	35	40	45	50
		Number of trees passed per minute							
1	88	4.4	3.5	2.9	2.7	2.5	2.2	2.0	1.8
1½	132	6.6	5.3	4.4	4.0	3.8	3.3	2.9	2.6
2	176	8.8	7.0	5.9	5.3	5.0	4.4	3.9	3.5
2½	220	11.0	8.8	7.3	6.7	6.3	5.5	4.9	4.4
3	264	13.2	10.6	8.8	8.0	7.5	6.6	5.9	5.3
3½	308	15.4	12.6	10.3	9.3	8.8	7.7	6.8	6.2
4	352	17.6	14.1	11.7	10.7	10.1	8.8	7.8	7.0



Pattern of trees hedged both sides in one direction.



Trees hedged both directions. Tangerines frequently are hedged both directions the first year.



This pattern extends the hedging operation over several years and reduces the crop loss in any one year. It is especially satisfactory when hedging is started well before branches interlock in the middles.

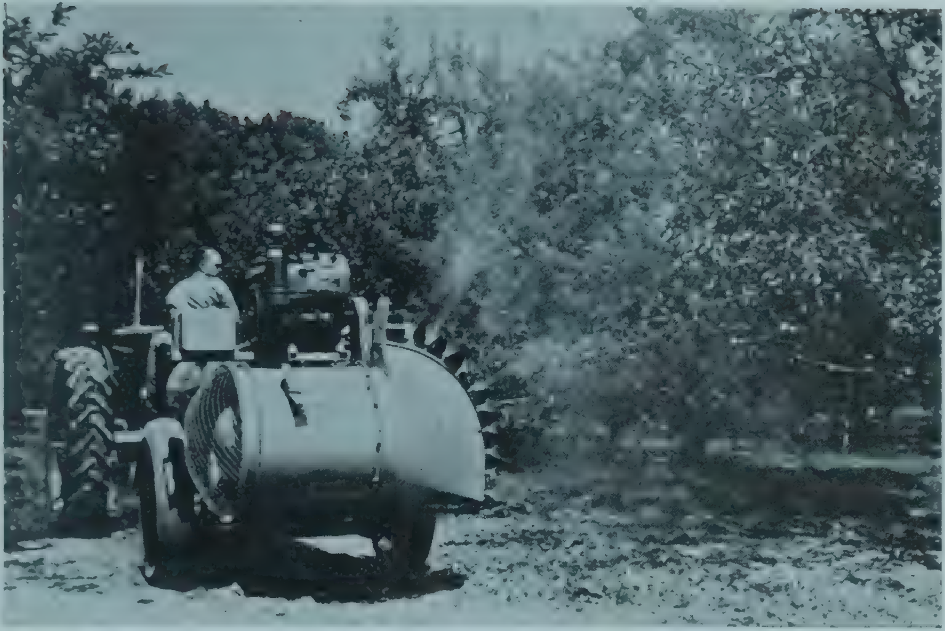


Figure 68. Myers Orchard Concentrate "Hang On" attachment delivering 16,500 cfm of air at 90 mph through an adjustable outlet provided with vanes. The company also makes a field crop attachment of the same capacity.
Courtesy, F. E. Myers and Bros., Ashland, Ohio.

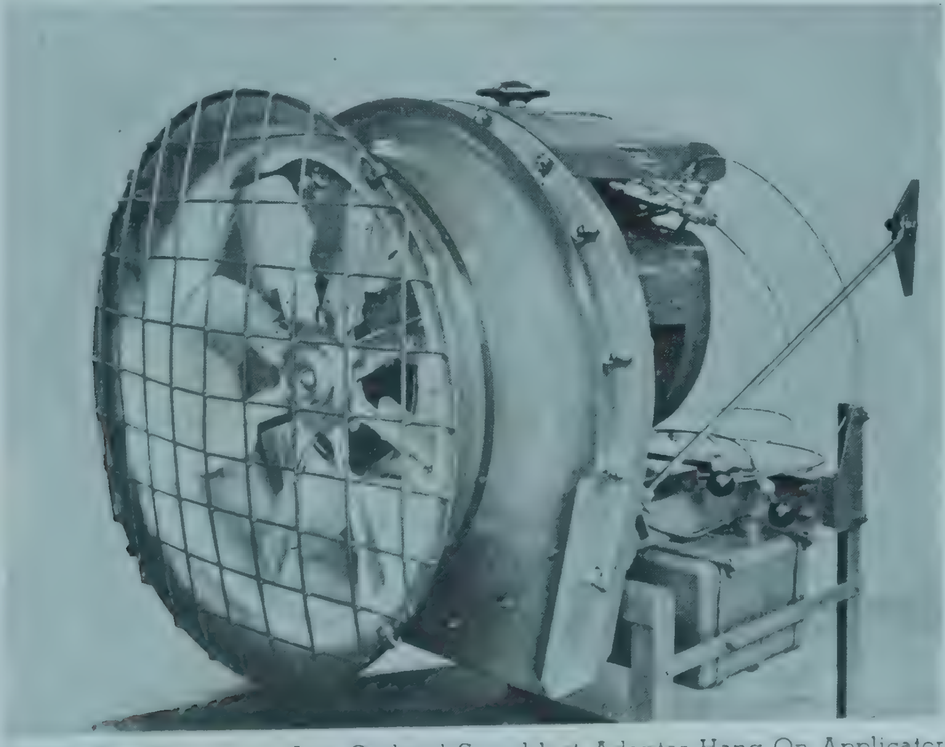


Figure 69. Oliver Iron Age Orchard Spra-blast Adaptor Hang-On Applicator
Courtesy of Oliver Corp.

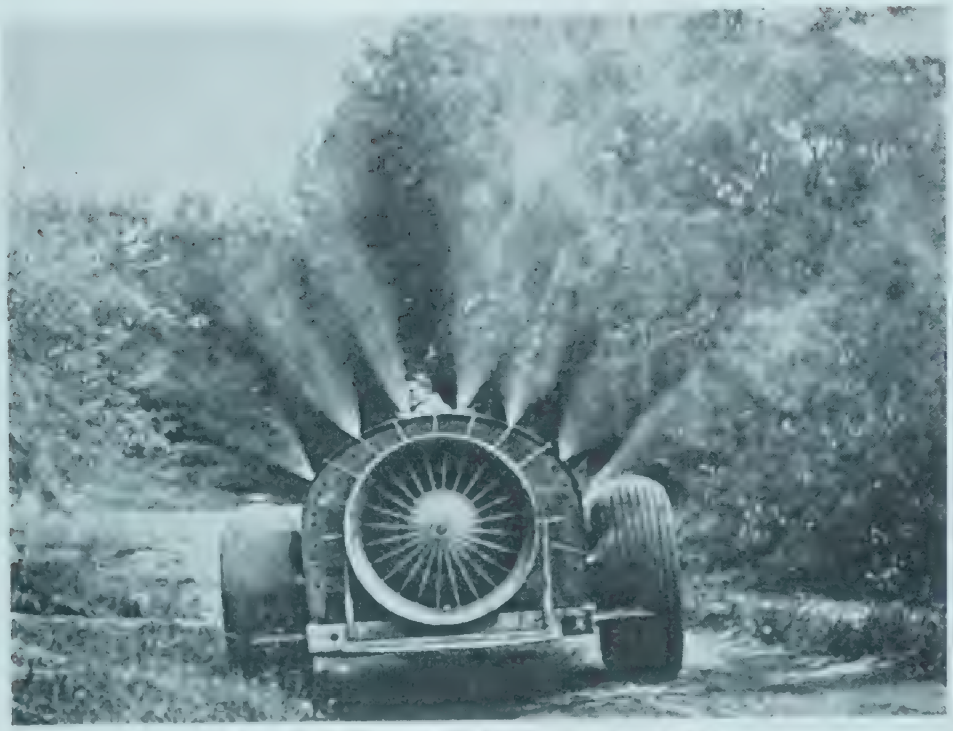


Figure 70 Cardox Aqua-jet Model 115

Courtesy, Cardox Corp.

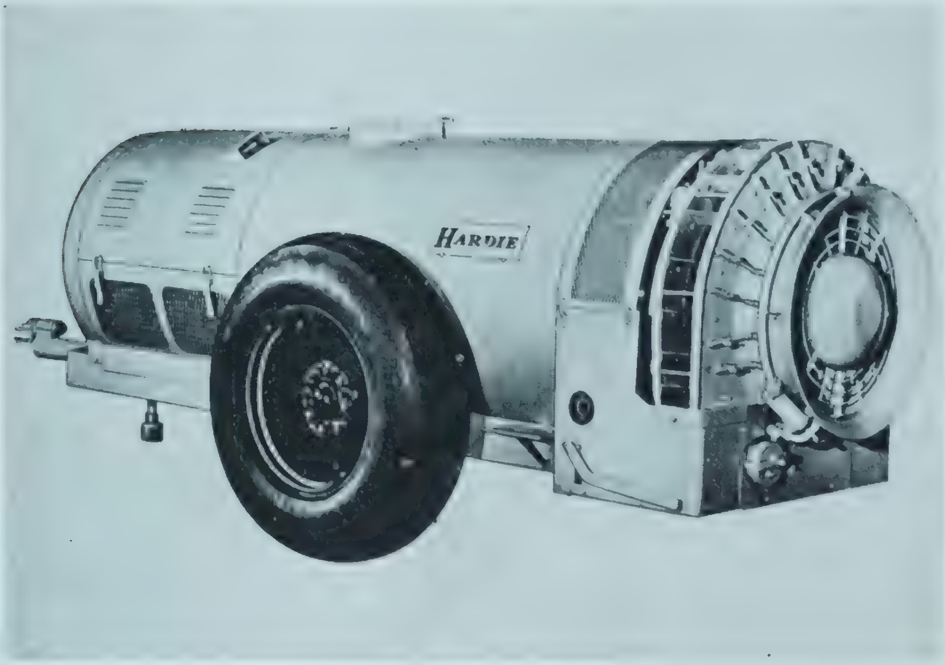


Figure 71. Hardie Model DF-26, equipped with a centrifugal pump with pressures up to 125 psi.

Courtesy, Hardie Mfg. Co., Hudson, Mich.

Nutrients,* as well as insecticides, are suited for application as concentrates. Copper, zinc, manganese, boron, and molybdenum can be applied in concentrate sprays. So far, urea sprays have not been widely used because of limited response and possible foliage injury from biuret—which is sometimes present as an impurity in commercial urea.

Use of the Light-Weight, 6 hp. Mist Blower for Fruit

THIS machine does not have sufficient capacity for treating large acreages of large orchard trees (Figure 43). It is most efficient for small orchards of large trees and for somewhat larger orchards of smaller trees depending on the number of trees per acre. Many large orchardists may find it useful for treating young trees, trees close to fences, in wet spots and other places that are difficult to reach with large, heavy rigs.

For treating large apple trees, the single, round outlet with one No. 3 or No. 5 Whirljet nozzle is required. If this outlet is used for peaches and other small trees in orchards, the machine should sit on the carriage vehicle in such a position as to point the outlet slightly backwards of the machine at an angle of 45 to 65 degrees to the line of travel. In the above uses, the application requires two men (driver and operator). Trees over 12 feet in height must be treated with the single, round outlet.

For treating peach trees, the single, round outlet is not as suitable as the fishtail outlet (Figure 65) or the triple round outlet (Figure 34) which make it possible for one man to perform the spray operation.

When treating trees with the triple outlet pointing at right angles to the line of travel, there are two weak spray and air streaks; one above and one below the center air stream. To eliminate these two weak strips, the machine is turned slightly so as to point the outlet backwards of the machine at an angle of 50 to 70 degrees to the line of travel. The outlet is then turned towards a horizontal position on the blower housing until the weak streaks are filled by the air-spray stream by the time it reaches the foliage.

FOR SPRAYING GRAPE VINES. Other workers have shown that concentrated sprays are effective in controlling grape insects and diseases, but no very satisfactory machine was available. It has been

---

* From information supplied by Dr. R. M. Pratt, Fla. Citrus Expt. Sta., 1956.

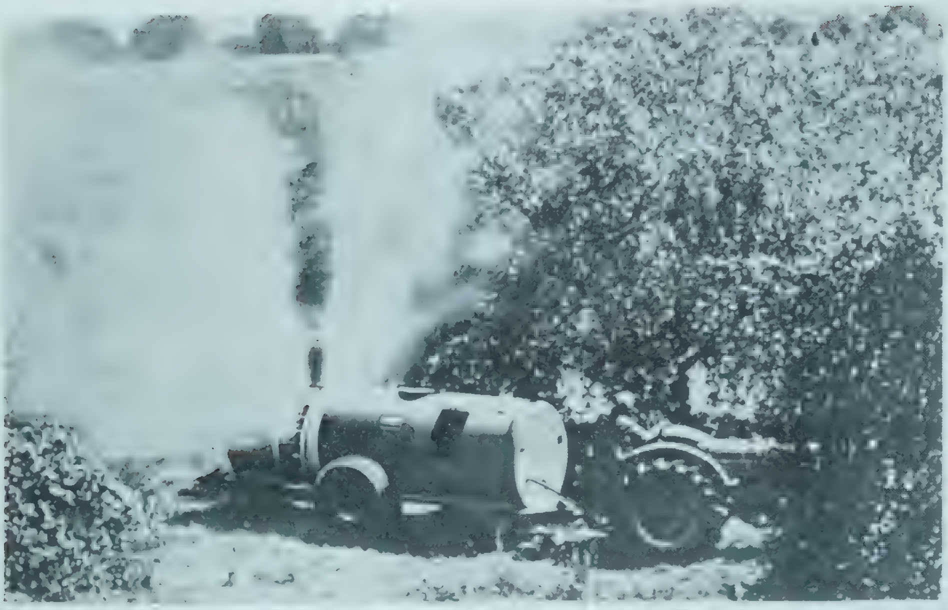


Figure 72. Model 40-D Speed Sprayer powered by Chrysler industrial V8 engine, 500 gallon metalized tank, and delivering over 60,000 cfm of air with a 40-inch axial blow fan.

Courtesy, John Bean Division, FMC, Lansing, Mich.

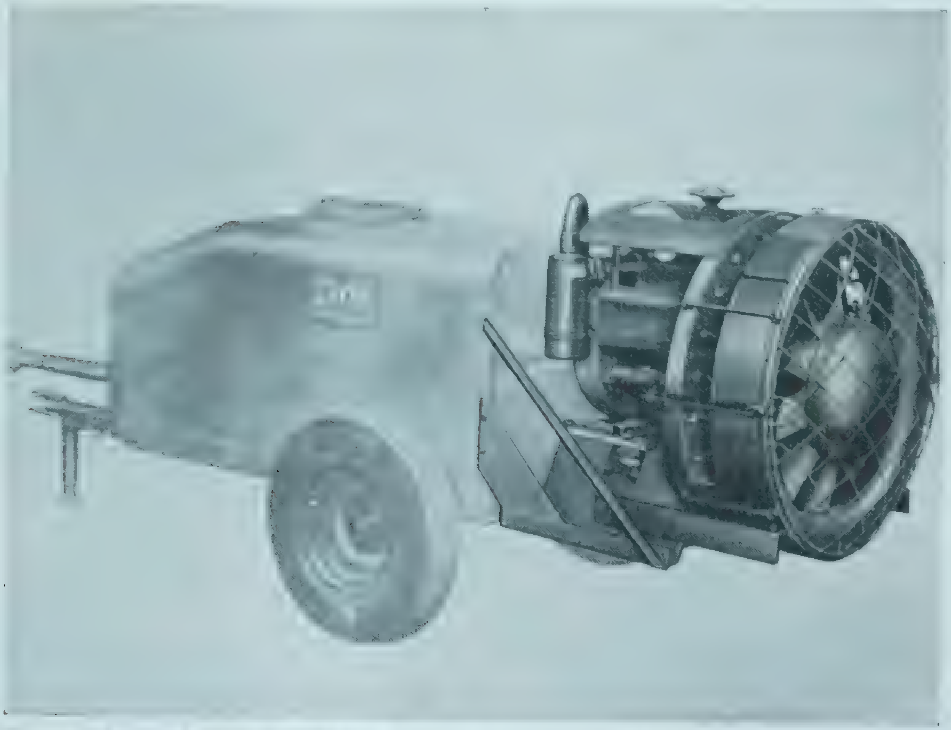


Figure 73. Model 12 Speedaire orchard attachment designed to convert high pressure units into air blast orchard machines. Uses 29 inch axial-flow fan to deliver 18,000 cfm of air.

Courtesy, John Bean Division, FMC, Lansing, Mich.

difficult to apply a low gallonage per acre because the rows are narrow (8 to 10 feet wide), and only one side of two rows can be covered at a time. A suitable machine must be light and compact enough to be carried between rows on a small tractor or trailer, and must cover the vines adequately on both sides of the machine while delivering a low gallonage per acre of finely atomized spray.

A Y-shaped, double round outlet (Figure 66) was made for applying spray to grapes. The two-outlets form an included angle of 80 degrees so that when the machine is traveling between two rows, each outlet points toward a row at an angle of 40 degrees to the line of travel. The two outlets are 3½ inches in diameter. Also a double fishtail outlet with two outlets nine inches long by one inch wide was made to increase the spread of the air stream. While this outlet increases the spread of the air stream, it does not seem to atomize the spray sufficiently for best coverage. On the other hand, the double round outlet arrangement results in good atomization, and its air stream is wide enough at the 80 degree included angle to cover the vines. If the angle is reduced to less than approximately 70 degrees, too much spray will be lost in the aisles between rows.

A flexible provision for adjusting the included angle of the Y can be effected by making a cross section of each of the two outlet pipes and then joining the cut ends with a flexible rubber hose (collar) to adjust for varying row widths.

The present outfit has been used with much success for the past three years by Dr. A. J. Brann of the New York Agricultural Experiment Station.

Dilute spray applications usually require 200 to 250 gallons per acre. For concentrate application, the total toxicants per acre should be reduced 20-25 percent and 15 to 20 gallons of total mixture applied per acre, using one No. 2 or No. 3 Whirljet nozzle in each air orifice and holding the pressure to about 15 p.s.i. Rate of travel should be between 2 and 3 m.p.h. At 2 m.p.h. travel, the rate of coverage with continuous spraying is 1.94 acres per hour for 8-foot rows, and 2.42 acres per hour for 10-foot rows. At 3 m.p.h. travel the rate of coverage would be 2.91 and 3.73 acres per hour, respectively. In the dormant season only one third as much toxicant need be used as for dormant treatments with hydraulic sprayers.

BLUEBERRIES. The light row crop mist blowers are well suited for treating low growing cultivated blueberries where the machine's

Table 51. Rate of coverage of trees with machine travelling at given speeds treating both sides of each row.*

Travel of machine m.p.h.	Distance between rows in feet	Acres per hour	Gallon per hour at**						
			2.5 gal. per acre	5 gal. per acre	10 gal. per acre	15 gal. per acre	30 gal. per acre	45 gal. per acre	60 gal. per acre
1	20	1.2	3.0	6.1	12.1	18.2	36.4	54.6	72.8
	30	1.8	4.5	9.1	18.2	27.3	54.5	81.8	109.0
	40	2.4	6.1	12.1	24.2	36.4	72.7	109.1	145.4
	50	3.0	7.6	15.2	30.3	45.5	90.9	136.4	181.8
1.5	20	1.8	4.5	9.1	18.2	27.3	54.5	81.8	109.0
	30	2.7	6.8	13.6	27.3	40.9	81.8	122.7	163.6
	40	3.6	9.1	18.2	36.4	54.5	109.1	163.6	218.2
	50	4.5	11.4	22.7	45.5	68.2	136.4	204.6	272.8
2	20	2.4	6.1	12.1	24.2	36.4	72.7	109.1	145.4
	30	3.6	9.1	18.2	36.4	54.5	109.1	163.6	218.2
	40	4.8	12.1	24.2	48.5	72.7	145.4	218.1	290.8
	50	6.1	15.2	30.3	60.6	90.9	181.8	272.7	363.6
3	20	3.6	9.1	18.2	36.4	54.5	109.1	163.6	218.2
	30	5.5	13.6	27.3	54.5	81.8	163.6	245.4	327.2
	40	7.3	18.2	36.4	72.7	109.1	218.2	327.3	436.4
	50	9.1	22.7	45.5	90.9	136.4	272.7	409.1	545.4
5	20	6.1	15.2	20.3	60.6	90.9	181.8	272.7	363.6
	30	9.1	22.7	45.5	90.9	136.4	272.7	409.1	545.4
	40	12.1	30.3	60.6	121.2	181.8	363.6	545.4	727.2
	50	15.2	37.9	75.8	151.5	227.3	454.6	681.9	909.2

---

* When treating each row from each of two sides (as above), the width of swath is half the distance between rows of trees. If one side of a row is treated on each side of the machine, the rate of coverage and rate of output would be twice that given in the table.

** Divide these figures by 60 to find gallons per minute.

outlet is above the plants. Special mounting is required for tall bushes, either mounting the machine higher or dividing the outlet into 3 to 5 round outlets to which are attached round, flexible hoses, 3 to 5 feet long. The end of each of these tubes contains a metal sleeve (outlet) with a nozzle in its center. These flexible outlets are supported over a simple, braced T-shaped frame to suspend them above the plants. Usually one nozzle (outlet) covers each row and points downward at an angle of 15 to 25 degrees with the ground.

CRANBERRIES. Heavy ground equipment cannot be operated on cranberry bogs. The wheelbarrow machine, the small skid model unit, and the knapsack mist blower can be used on cranberry bogs for applying insecticides, fungicides, and nutrients. Large acreages of bogs would require several such units.

Studies to date indicate effective volumes of 5 to 10 gallons per acre for insects, excepting the gypsy moth which can be controlled with one pound of DDT in two gallons of mixture per acre.

Commercial Air Blast Concentrate Machines for Orchards

Descriptive material, data, and several pictures of various commercial machines are given below.

Non-Blower, Low Gallonage Equipment

THE advent of the low gallonage concentrate machine for controlling pests of row crops,* and for weed control, has ushered in a major revolution in mechanized agriculture. Already over 25 million acres are sprayed annually with this equipment. Crops included in large scale treatments are cotton, corn, flax, vegetables, alfalfa, clover, small grains, and pastures. Additional uses are bound to arise as new agricultural chemicals are developed including nutrients, fertilizers, and plant growth hormones.

The apparatus is relatively simple, light, and cheap and does not require a blower to help atomize the spray or to drive it to considerable distances.

A second type of non-blower applicator uses a compressor to atomize the spray with compressed air, with or without the air blast of a fan to carry it. Very fine atomization can be produced with compressed air, but a blower is required for tree application. The

---

* Potts, S. F. Equipment available for applying concentrated sprays. B.E. and P.Q. E574, U.S.D.A. 1942.

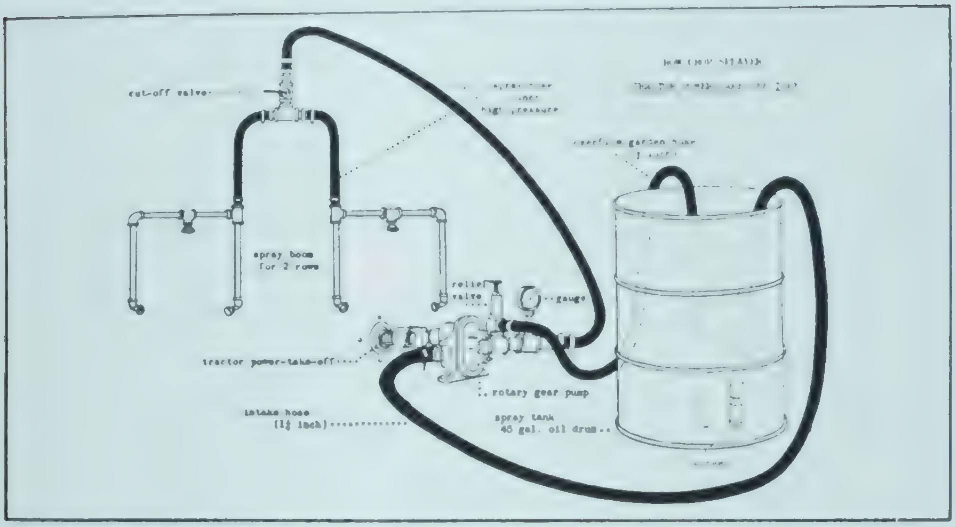

cut-off valve
high pressure
spray boom
for 2 rows
relief
valve
gauge
tractor power-take-off
rotary gear pump
intake hose
(1½ inch)
spray tank
45 gal. oil drum

Figure 74. Row-crop sprayer unit, showing relative positions of pump, spray tank, boom, cut-off valves, and hoses.

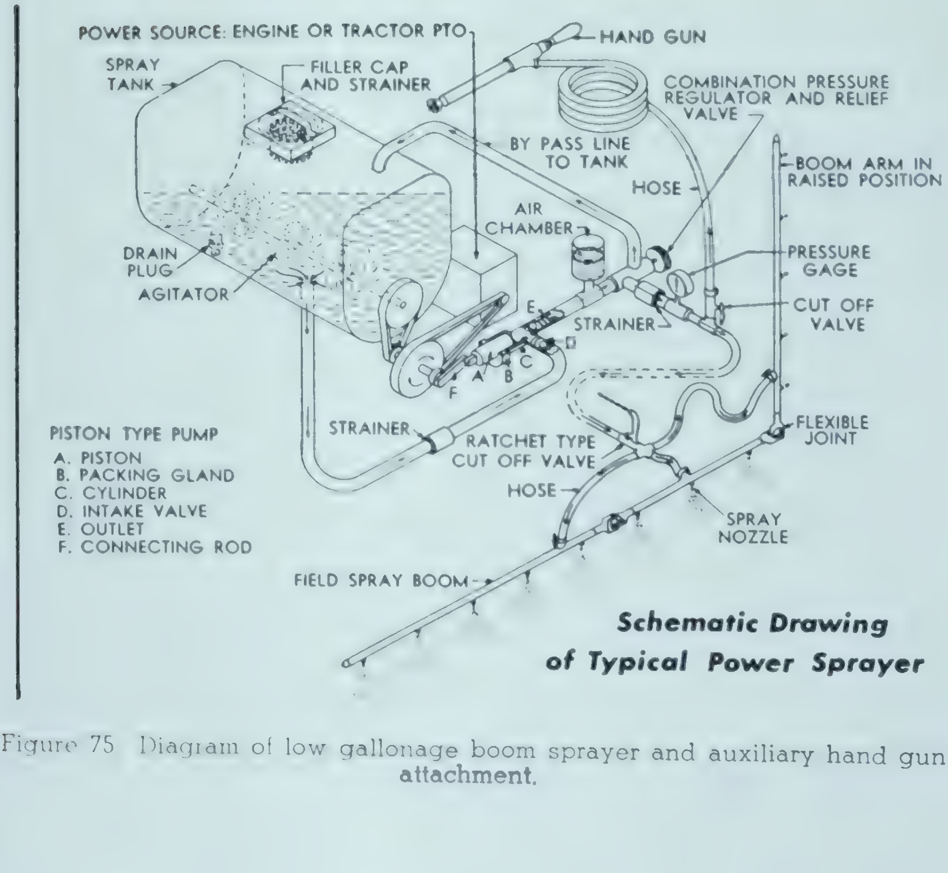

POWER SOURCE: ENGINE OR TRACTOR PTO
HAND GUN
SPRAY
TANK
FILLER CAP
AND STRAINER
COMBINATION PRESSURE
REGULATOR AND RELIEF
VALVE
BY PASS LINE
TO TANK
BOOM ARM IN
RAISED POSITION
HOSE
AIR
CHAMBER
DRAIN
PLUG
PRESSURE
GAGE
AGITATOR
E
STRAINER
CUT OFF
VALVE
D
A
B
C
F
PISTON TYPE PUMP
A. PISTON
B. PACKING GLAND
C. CYLINDER
D. INTAKE VALVE
E. OUTLET
F. CONNECTING ROD
STRAINER
RATCHET TYPE
CUT OFF VALVE
FLEXIBLE
JOINT
HOSE
SPRAY
NOZZLE
FIELD SPRAY BOOM
Schematic Drawing
of Typical Power Sprayer

Figure 75. Diagram of low gallonage boom sprayer and auxiliary hand gun attachment.

compressor makes a more expensive, and always a more complicated, machine.

The basic requirements of low gallonage rigs include a tank for the insecticide; a pump with necessary pressure regulator, pressure gauge, and liquid by-pass; strainers; spray shut-off and control valve; hose; adjustable nozzle arrangement; and low volume, finely atomizing nozzles.

The spray mixture is pumped through hydraulic atomizing nozzles, such as oil burner and fan (flat) spray nozzles, that deliver 1 to 12 gallons per nozzle per hour at 20 to 75 pounds pressure. The nozzles may project the spray in the form of a cone or in a flat, fan-shaped sheet. In the former case, they are usually spaced 12 to 14 inches apart on a boom; in the latter, they may be spaced about 18 to 24 inches apart. Special adaptations can be made for cultivators and for high clearance vehicles such as are used for spraying or detasseling corn.

This type machine is limited in use to low growth and cannot be used to spray entire trees. It is useful for applying insecticides and herbicides in solution or emulsion form and is employed for the low gallonage application of 2,4-D concentrates. The system is limited by the fact that with extremely low gallonage it cannot atomize the spray material to a sufficiently fine degree. From 20 to 40 gallons per acre of semi-concentrated spray suspension have been applied successfully to row crops for insect and disease control with these machines, using two to three, No. B1, B2, or B3 Whirljet nozzles, or the equivalent, with $\frac{1}{16}$- and $\frac{3}{32}$-inch orifices, respectively, per 3- to 4-foot row.

The use of a large orifice and appropriate screens is required to prevent clogging by suspensions of solids. This results in a high output of fairly coarse spray. Line and nozzle screens of suitable mesh and surface area are important. Nozzle screens finer than 60 mesh may clog with any mixture, and screens finer than 20 mesh are not satisfactory for suspensions. This type of application may not provide sufficient coverage for good plant disease control with less than 6x concentration.

Simple diagrams of low gallonage units are shown in Figures 74 and 75.

The several modifications or adaptations of equipment for different types of application are discussed, including very low gallonage delivery for cultivator, row, and broadcast application, application of fungicides and wettable powders at higher volumes, and the operation of high clearance sprayers.

Low Gallonage Equipment for Cotton and the South

THE most outstanding step taken in the direction of mechanization in the handling of crops has been the recent rapid development, and the widespread acceptance, of spray equipment by the southern cotton growers for insect control, weed control, and cotton defoliation.

Only a few years ago no spray equipment of any kind was to be found on the average farm. Some of the livestock, fruit, and vegetable growers had spray equipment, but it was of the high gallonage, high pressure type. With the development of low gallonage spraying for weed and insect control, the picture has changed until now a high percentage of cotton farmers own or have access to some kind of sprayer.

According to Waters (1953, p. 34) "The first low gallonage weed sprayers appeared in 1947. The first cotton insect control tests with sprays were made in 1948 and the first commercial usage was in 1949. Dependence upon sprays has spread so rapidly that within three years, 85 per cent of the cotton insecticides sold in Texas (1953) was in liquid form for use in sprayers. (Figures 76 and 77).

"This increase in use was due to several factors. The great benefit from early season insect control was the biggest single factor. Wide-spread educational activities by state, federal and commercial agencies contributed their influence. New chemicals with the ability of doing a better job were important; and last was the spray method of application with its lower equipment and chemical cost. Its greater effectiveness is especially useful in windy weather which is common when early season applications should be made.

"In general, it has been found that the low gallonage cotton sprayer can be used successfully for insect control elsewhere, such as on vegetables, grain and forage crops. At one time, many farmers who have only a few cattle would never have considered treating them for insects, but now they add a hand gun to their cotton sprayer and treat their cattle."

Most cotton sprayer manufacturers now offer models that can be used along with cultivator equipment, and most have now standardized on three-gallon-per-hour hollow cone nozzles.

NEW NOZZLE DESIGNS. One nozzle manufacturer has changed the internal design of the hollow cone nozzle to reduce the incidence of plugging. Most hollow cone nozzles have the one outside opening and two slots leading into a swirl chamber back of this opening. This particular manufacturer has designed a swirl chamber that functions quite well with only one slot. By combining the area of these two slots into one, the cross sectional area has been doubled. In addition, the slot area and outside hole area, are now made about the same size.

This gives the largest possible opening. Thus in a three gallon per hour tip of this style, the smallest constriction in the nozzle is .033 inches across. With two slots, the smallest opening was .019 inches across. In the one gallon per hour tip, this change increased the diameter of the smallest constriction from .010 to .018 inch, making the one-gallon tip relatively free of clogging trouble. Further changes in the shape of the swirl chamber made this style of nozzle function well at a much lower pressure than before. This point is especially important for hand spraying. For power sprayers, it means less pump wear.

It has been found that for cotton insects, the hollow cone tip is superior to the fan tip. For aphids and mites on grain, both styles have proved satisfactory. Thus, to spray grain for control of these pests, a farmer can take his cotton spray rig, set the nozzles so one points downward about every twenty inches, and do a good application job using approximately five gallons of total spray per acre.

OTHER USES for the cotton sprayer are rapidly being developed.

By adding a special bracket and hoses, one can spray weed control materials on the row behind the planter or press wheel. For this band spraying, one nozzle manufacturer now makes an even spray fan tip. Ordinary fan tips make a heavier deposit at the center, so that when the patterns overlap on a weed boom, an even spray results. This new tip for hand spraying gives an even deposit all the way across the fan.

By adding special shoes, nozzles, and hoses, the sprayer can be used to spray selective herbicidal oils on the weeds (especially grass) in young cotton, in wet seasons when weeds tend to get out of hand.

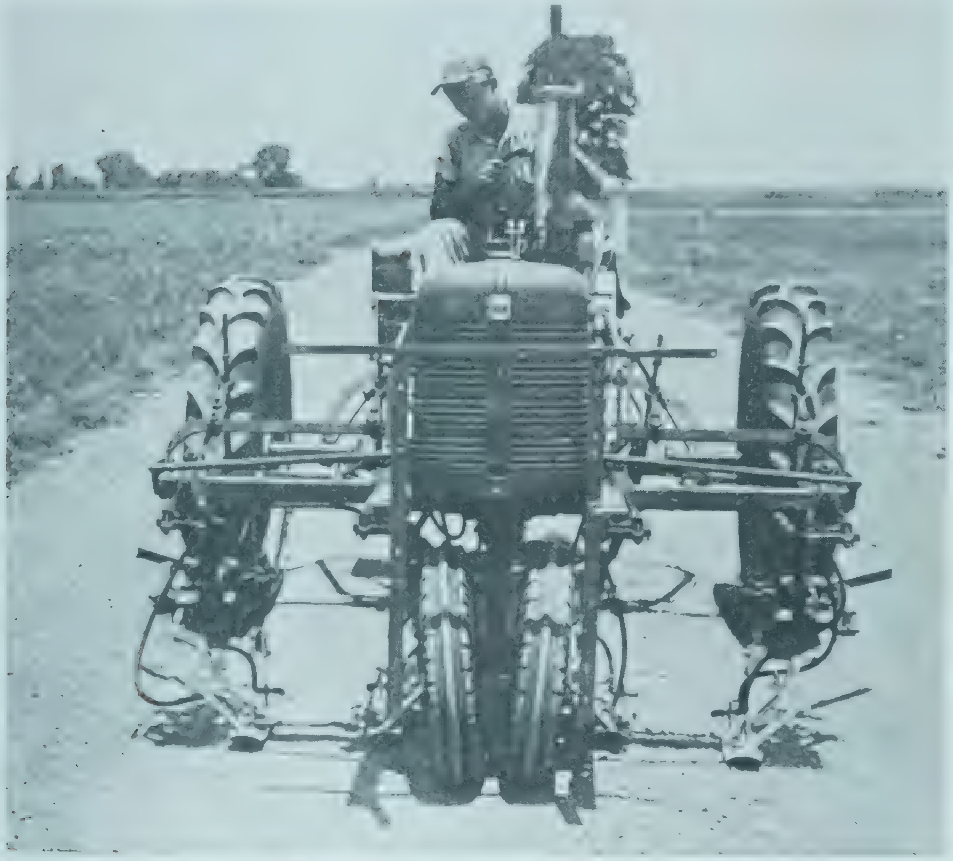


Figure 76. Combination cultivator and mist sprayer.
Courtesy Delta Branch Experiment Station, Stoneville, Miss.

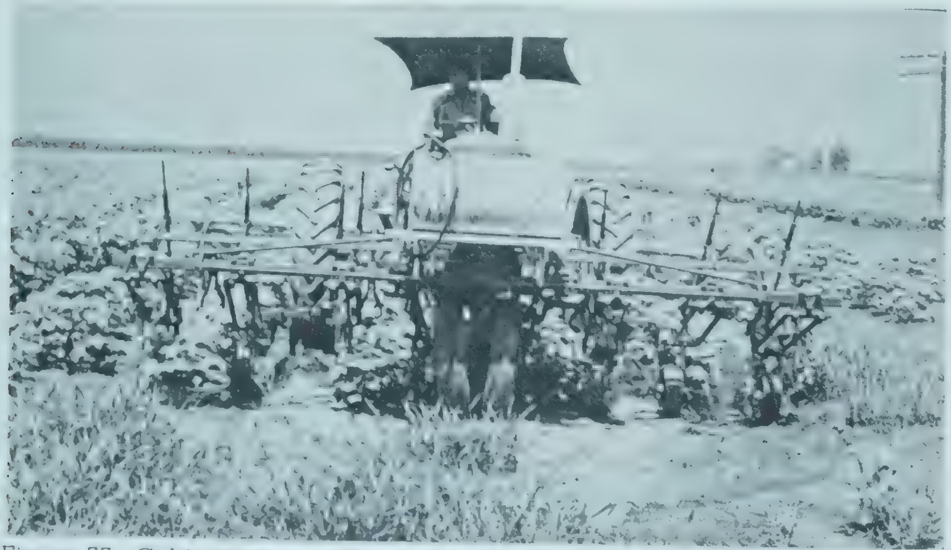


Figure 77. Cultivator-low gallonage sprayer with tank drum mounted in front.
Courtesy, Delta Branch Expt. Sta., USDA, Stoneville, Miss.

Field trials for the past two years have resulted in efficient designs for these types of applications.

VERSATILITY FEATURED. The cotton sprayer is now commonly used in defoliation and leaf killing. For short cotton (24 to 30 inches high) the 3-nozzle cotton drops and nozzle outlets are sufficient. For cotton three to four feet tall, special long drops with double swivel nozzles on the end are needed to reach inside. For taller cotton, it is not practical to drag long drops from the ordinary boom through the cotton. For this tall cotton (4½ feet or taller) a special type of high clearance sprayer is required.

The high clearance sprayers designed for corn are entirely unsatisfactory for cotton, however. These corn sprayers are made for an upright crop with no leaves or crop near the base. In cotton, they drag or run over the lower branches and fallen plants, knocking off bolls and damaging the plant. A high clearance cotton sprayer must have smooth lifting type shields that go from near the ground to the full clearance height of the machine. The driver must be able to raise the shield a foot or so for turning over the ditches at the end of the row. There must be adequate power and an especially low gear for turning on these row end ditches.

COMPRESSED AIR HAND SPRAYERS FOR COTTON. Special hand booms are now available for the cotton grower who has only a few acres to spray. A long handled boom offers safety for the operator. For early season one-nozzle-per-row treatment, a man can easily treat an acre an hour. With equipment costing $25 or less, a man can treat four to six or eight acres in one half to one day.

The secret of success of this hand application by the common laborer is to use only one gallon of spray in a 3½ or 4 gallon compression knapsack sprayer. One good pumping will deliver the entire gallon at an adequate pressure. If two gallons are used, the sprayer must be repumped at the proper time. Most common laborers lack the judgment of when to repump. If a 1.5 gallon nozzle is used, one gallon of spray will last over 40 minutes and will spray about two thirds acre for early season. By using two hand wands, the acreage treated per hour can be doubled.

Cultivator Spray Rig for Farm Tractor

A SIMPLE spray rig can be constructed and attached on the regular tractor cultivator, and spraying performed in conjunction with the cultivating operation. Hence, there is no additional power

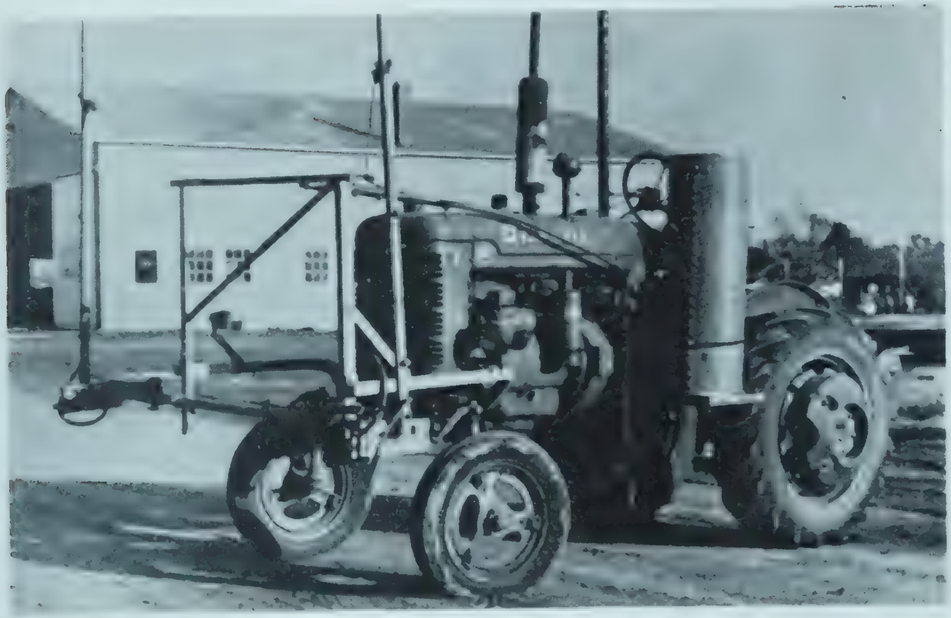


Figure 78. One row straddle tractor with vertical tank mounting and conventional broadcast boom

Wooten, Smith, and Meek, 1950. *Courtesy, Miss. Agr. Expt. Sta. and U. S. D. A. Agr. Eng. and Entomologists cooperating*

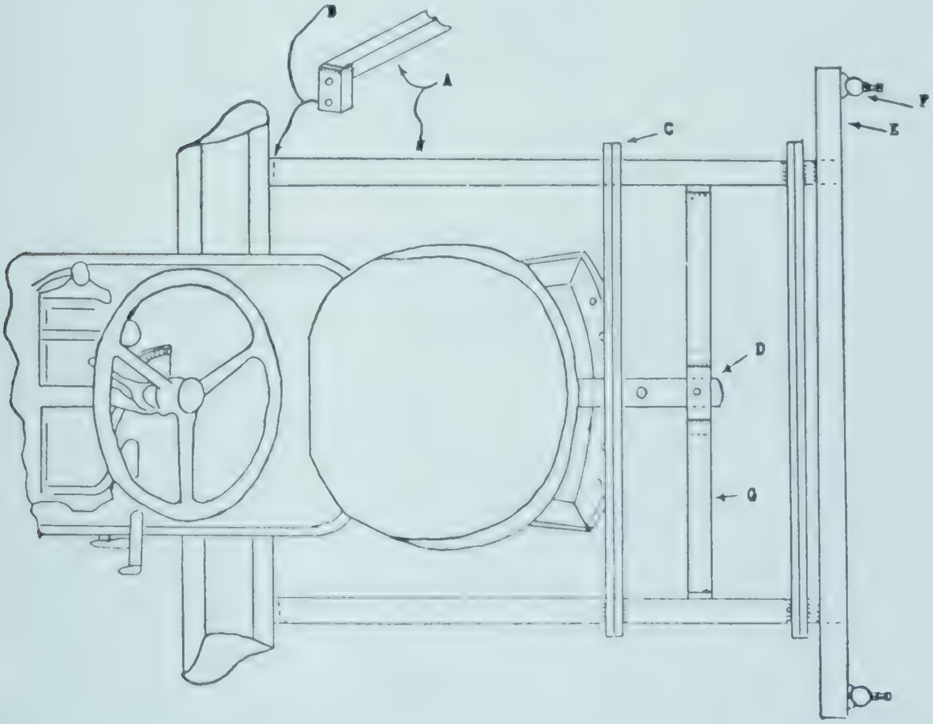


Figure 79. Sketch showing top view for the three-point suspension type of tank mounting.

From Wooten, Smith, and Meek, 1950, p. 8.

or labor charge for insect control. Mixing the insecticides and filling the spray tank are the only additional operations necessary. This greatly increases control efficiency and reduces costs (Figure 78).

A number of spray rigs are available to farmers. However, few had been designed specifically for cotton or for use with the regular cultivating equipment found on tractors. This discussion is to assist those farmers who are not able to procure satisfactory spray equipment locally or who prefer to build their own machines. (Wooten, Smith and Meek, 1950)

The wide variety of makes and models of tractors together with the many combinations of equipment used with them makes it impossible to give specific plans for the design and arrangement of the rig in every case. The simplicity of the rig itself should make it possible for the farmer to construct his own machine after a careful study of sketches, photographs and instructions. Where there is no farm shop it will, of course, be necessary for some of the parts to be fabricated at some local machine or repair shop. Imagination, ingenuity and mechanical skill will allow many farmers to adapt the basic principles of the machine to their peculiar conditions of operation.

The following useful information on cultivator attachments is taken from Mississippi Agricultural Experiment Station Bulletin #472. (Wooten, et al, 1950).

"TANKS. While special tanks are available for spray machines, the average farmer will prefer to use one of low cost that is readily available. There are three convenient sources of supply. Many insecticide manufacturers ship their materials in 32-gallon metal drums which make excellent tanks. The standard 50-gallon oil drum is available for larger gallonage operations, or, where a small drum is indicated and the insecticide drum is not available, a 100-pound grease drum may be used.

"The insecticide and oil drums are fitted with two openings in one end. They are mounted in the horizontal position with the smaller opening at the lowest point. This opening usually has ¾-inch pipe threads and a ¾-inch by ½-inch bushing is used to reduce the size of the opening to take the outlet hose connections.

"The large opening is fitted with a street ell of a size determined by the opening itself. The regular drum plug then is used in the street ell as a filler cap. The use of the street ell provides a convenient means of filling the drum, Figure 79.

TANK MOUNTINGS. "The mounting of the tank is a problem peculiar to the individual tractor and its equipment. No set manner of building the mount or specifying a particular location can be made. The farmer must adapt his mounting arrangement to his equipment.

"The vertical type of tank mount is often used on tractors having mounting pads for the attachment of implements. Here a bracket is made to fit the tank to be used and mounted with cap screws in the same manner as implements. This type of mounting will be found especially suitable for the small one-row outfits.

"Where horizontal mountings are to be employed, angle irons welded to cross members offer a simple construction for the tank cradle. The angles may be 1½-inch by 1½-inch or 2 inches by 2 inches of any thickness available and are cut the length of the tank. They are placed on the cross members with the angle up (as shown in Figures 91 and 93) and welded in position after spacing them to fit the diameter of the tank. The tank should be protected from the cradle by pads of belting, rubber, or some such resilient material. Discarded belts, inner tubes, etc., offer a source of supply. Rods or straps serve to hold the tank firmly in place. These straps should be formed to fit the tank and may be welded to the cradle at one end. One end should, however, be capable of being detached for removal of the tank. A bolt welded to the end of the strap and passing through a hole drilled in one of the angles of the cradle provides a positive means of adjusting the straps and allows quick removal of the tank when necessary.

"Two general locations for the tank on larger tractors are front mounting and rear mounting. Where the tractor is equipped with a flame cultivator, anhydrous ammonia application machine, etc., the front mounting is used. Many times the front mounting will be preferred when the rear section of the cultivator is attached. When this mounting is used, the mount may be attached to either the main frame or truss rods of the cultivator. The attaching members should be so constructed as to readily accommodate the cradle and tank and at the same time be amply strong to stand the shock and vibration incidental with field operations.

"Where the rear mounting is employed, two types of mounts are the rule. In one, channel irons or pipes are used to form the members supporting the tank and cradle. This construction is similar to that employed in attaching many flame cultivators and anhydrous ammonia machines. Pipe or tubing is usually the preferred material with 3-inch pipe being more commonly used. The channels, when used, should be about three inches in size and at least ¼-inch in thickness.

"The side members of the mount are extended forward from the top of rear axle housings of the tractor and are attached with bolts and straps to the main frame or other attaching points near the middle of the tractor. "U" bolts secure the members to the rear axle housings. Care should be exercised to see that these side members extend far enough to the rear so as to clear the rear wheels should it be desired to mount a spray boom on them. Also, there must be clearance between the tank and the seat when the latter is in the lowest possible position. This is necessary to prevent interference of the seat and tank when operating or transporting the machine over rough fields or roads.

"Another type of rear mounting is used on tractors having a draw bar which is always attached. This is a three-point suspension type in which two pieces of angle are cut extending from the rear axle housings of the tractor rearward so as to provide clearance for wheels and seat as described previously. Figure 79 shows the construction and these angles as A. These angles are usually three inches by three inches by ¼-inch. To their forward end a short piece of the same material is welded, extending downward, and is drilled to accommodate the implement attaching pads on the axle housing. This is shown as B on the drawing. A piece of heavy strap iron (½-inch by 2½ inches) is cut approximately 10 inches in length and drilled in the center for bolting to the tractor draw-bar as is shown by D. Next, two pieces of angle iron, G, are cut to extend upward from the ends of this strap to the angle irons A when they are parallel with the ground. These angle irons, G, form a V brace. The lower ends of this V are welded to the ends of the plate. In order to facilitate attaching the complete mount to the tractor the upper ends of the angle irons, G, of the V are bent to lie flat against the sides of the angle irons A. The two members are then drilled to accommodate a ½-inch machine bolt and are bolted together. The angle irons C are next cut to fit the tank length and are positioned to form the tank cradle, being welded in place. When the rear mounted boom is used, it is attached as shown at E and F. It is described in detail later.

"In order to assure a positive supply of material from the tank to

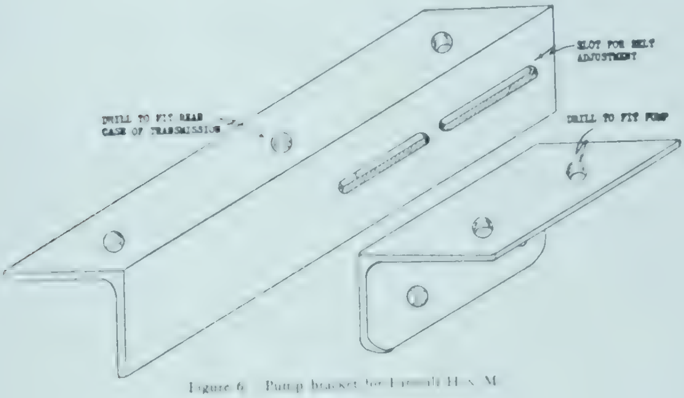

SLOT FOR BELT ADJUSTMENT
DRILL TO FIT REAR CASE OF TRANSMISSION
DRILL TO FIT PUMP

Figure 6. Pump bracket for Farmall H & M

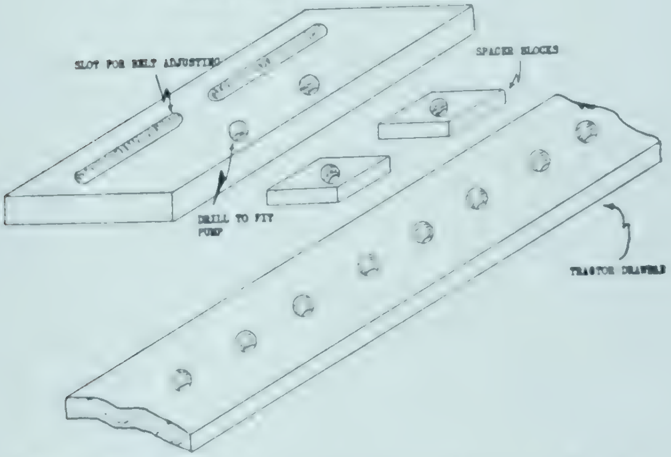

SLOT FOR BELT ADJUSTING
SPACER BLOCKS
DRILL TO FIT PUMP
TRACTOR DRAWBAR

Figure 80. Pump mount for John Deere A & B

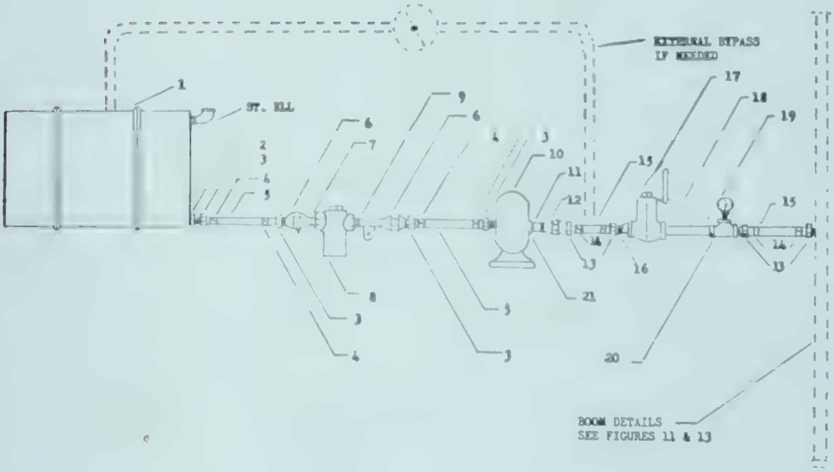

EXTERNAL BYPASS IF NEEDED
1
ST. ELL
2
3
4
5
6
7
9
6
4
3
10
11
12
15
17
18
19
15
14
13
16
14
13
8
3
4
5
3
21
20
BOOM DETAILS SEE FIGURES 11 & 13

Figure 81. Plumbing schematic. Numerals refer to item numbers in bill of materials.

Wooten, Smith, and Meek, 1950.

the pump at all times, it is important that the tank be mounted at the level of, or preferably slightly above, the pump.

Pump Mountings. "Pump drives are of three types. One is a pump connected directly to the power take-off shaft of the tractor by means of an adapter connection. While most of the newer tractors have power take-off shafts built to standard, it is always advisable to give the diameter of the shaft when ordering the pump and adapter. The second type is also a direct connected unit but it attaches to the power take-off shaft directly, no adapter being necessary. Here again the power take-off shaft size should be given.

"The third is a standard pump designed to be driven by belts through sheaves or pulleys. Pumps of this type are mounted on the tractor, with provision made to allow adjustment for the tightening of the belt. The size of the pulleys or sheaves used and the mounting location will determine the length of the belt. The sheaves used on the power take-off shaft and pump shaft should have a ratio of not less than 3:2, nor more than 2:1.

"Mountings for the pump will vary with individual tractors (Figure 80). The pump mounting may be attached to the transmission case, or it may attach to the tractor draw bar. Modifications may be made so that a similar mounting can be fabricated for the particular make and model of tractor. A belt-driven pump is shown in Figure 86. Care should be exercised to adjust the belt for tension. A belt that is too loose will cause the pressure to fluctuate because of slippage. One that is too tight will cause undue friction between the shaft and bearing, resulting in excessive wear and subsequent pump failure.

LINE STRAINER. "The line strainer, located between the pump and the tank, is most important as it serves a dual purpose in protecting the pump and nozzles from foreign matter. Line strainers are obtainable from the manufacturers of spraying equipment and accessories."

A felt intake strainer, to go on the end of the intake hose, to remove fine abrasive silt from the water has been introduced by two manufacturers. Such strainers do a more efficient job of filtering the water, but by the same token must be cleaned more often when used with dirty water.

KEEP THE MIXTURE CLEAN. Clean water should be used in all cases and the materials mixed thoroughly. Any material placed in the sprayer tank should first be strained. A convenient method of

Cultivator Spray Rig for Farm Tractor

See Figure 81
Bill of Materials

Item	Description	Size	4-row	2-row	1-row[a]
	Tank to Boom (Plumbing Schematic)				
1	Tank	15,32,55 gal.	1	1	1
2	Street ell	2"	1	1	
2	Bushing, reducing	¾" to ½"	1	1	
3	Shank, hose male	½"	4	4	
4	Clamp, hose	½"	4	4	
5	Hose, neoprene[b]	½"	10′ to 20′	10′ to 20′	
6	Union, ground	½"	2	2	
7	Nipple	½" close	1	1	
8	Strainer, line		1	1	1
9	Nipple	½" x 4"	1	1	
10	Pump	½"	1	1	
10	Pump	¼"			1
11	Nipple	¼" close	1	1	2
12	Union, ground	¼"	2	2	2
13	Shank, hose male	¼"	4	4	8
14	Clamp, hose	¼"	4	4	8
15	Hose, neoprene[b]	¼"	20′ to 30′	20′ to 30′	10
16	Bushing, reducing[c]	⅜" to ¼"	1	1	1
17	Valve, quick cutoff	⅜"	1	1	1
18	Nipple	¼" x 4"	1	1	1
19	Gauge	0 to 100 p.s.i.	1	1	1
20	Tee	¼"	1	1	1
21	Bushing, reducing	½" to ¼"	1	1	
	External pressure regulator[d]	½"	1	1	1
	Boom (Front Drop)				
	Nipples	¼" close	4	1	
	Union, ground	¼"	4	1	
	Cross	¼"	5	2	1
	Ell, 45 degrees	¼"	8	4	2
	Ell, 90 degrees	¼"	8	4	2
	Pipe	¼"	20′	10′	5′
	Tee	¼"	5	2	
	Shaft collar	⅝"	4	2	1
	Hose end	¼"	6	2	
	Clamp, hose	¼"	6	2	
	Boom (Rigid less Main Pipe)				
	Coupling, hose	¼"	12	6	
	Nipple	14" x 6"	5	3	
	Ell, 45 degrees	¼"	2	2	
	"Y"[e]	¼"	3	1	
	Caps	1¼"	2	2	
	Pipe, D.S.	1¼"	14		
	Pipe, D.S.	¾"		8	
	Caps	¾"		2	
	Jets				
	Hollow cone	¼" male	12	6	3
	Plugs, pipe	¼"	8	4	2

---

[a] In fabricating one row machines, ¼" hose and fittings are used throughout.

[b] Hose lengths are approximate and are cut to fit individual installations.

[c] Optional.

[d] If the pump is not equipped with an internal pressure regulating device then the external pressure regulator will be needed with additional hose and fittings.

[e] If it is impossible to obtain a "Y" fitting from stock, one may be fabricated. This will require an additional ell for a 2-row machine and three for a 4-row machine.

straining the materials and filling involves the use of a large funnel equipped with a screen of brass cloth in the throat. Such funnels, commonly used for straining the fuel into tractor tanks, can be obtained locally.

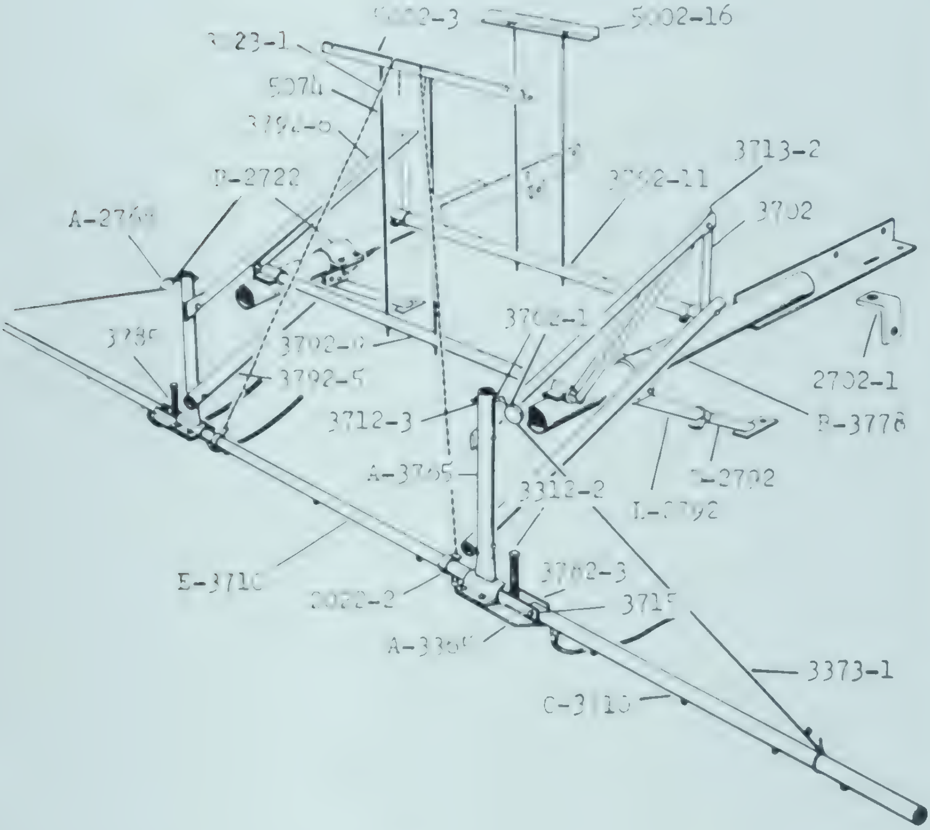
Any material still in the tank at the end of the operation may be drained into a covered container and used with the following day's supply. A thorough mixing of the old and new materials is necessary.

In any event, at the end of each day's operation the tank should be drained and the system thoroughly cleansed. It is advisable first to remove all nozzle tips and strainers, which should be washed in solvent or gasoline and left overnight in this material. The container in which the tips and strainers are placed should be covered. Next, the tank should be drained and flushed with clean water. The line strainer should be removed, thoroughly cleansed and reinstalled. After all connections are tight, several gallons of clean water should be pumped through the system to insure proper flushing.

HOSE. "The hose should be Neoprene both inside and out, so as to withstand the action of the chemicals, oil, etc. This type of hose is sometimes referred to as hot oil hose. The hose in the system from the tank to the pump is ½-inch and from the pump on through the boom and to the nozzles ¼-inch hose is used. Both ½-inch and ¼-inch hose ends will be required (see bill of materials) together with the necessary clamps."

BOOMS. "The type of boom used, its installation and location must, as in the case of tank mountings, be largely a matter of preference determined by the equipment being used on the tractor. Several types are satisfactory, the location of the spray nozzles with reference to the plants being basically the same on all.

"The rear mounted boom is on the tank mounting in which the cradle has been modified to provide attaching points. Vertical pipes or standards are carried in set collars attached to the attaching points of the tank mounting. These standards are of 1-inch pipe approximately 30 inches long. To their tops a short piece of angle iron is welded extending toward the rear. These angle irons are drilled to accommodate a standard automobile muffler clamp of the proper size for the cross pipe or boom. The standards may be raised or lowered, giving height adjustment to the boom and the boom may be rotated in the muffler clamps for rotational adjustment. For still greater


5002-3
5002-16
3723-1
5074
3792-6
B-2722
A-2768
3785
3792-9
3792-5
3712-3
3762-1
3792-11
3713-2
3702
2702-1
B-3778
A-3765
3312-2
D-2792
L-2792
E-3710
2022-2
3782-3
3715
A-3365
3373-1
C-3710

3702	10¼″ Front Pantograph Angle
2702-1	Angle Rear Mounting
5002-3	19″ Rear Angle for Top of Drum
5002-16	7″ Front Angle for Top of Drum
C-3710	End Boom Section
E-3710	Center Boom Section
3312-2	5/8″ x 7″ Machine Bolt for Hinge
3712-3	5/16″ x 6½″ Machine Bolt for Pulley
3713-2	187½″ Diagonal Brace
3715	Spacer Bushing
B-2722	2 Piece Clamp for Leg
2022-2	1″ Strap Hanger
3021-1	5′ Boom Support Chain
3723-4	6½′ Boom Support Chain
3762-1	Support Pipe for Pulley Bolt
A-3365	Hinge Base
A-3765	Hinge Upper Piece
A-2768	Rope Pulley
3373-1	16′ Rope
5074	39½″ Drum Rack Rod
B-3778	2¼″ OD Straight Arm for Drum Rack
3782-3	5″ Hinge Support
3785	Hinge Spring
D-2792	Lower Telescoping Leg
L-2792	Upper Telescoping Leg (Includes U Bolt and Saddle)
3792-5	34″ Lower Pantograph Tube, 1½″ OD
3792-6	34″ Upper Pantograph Tube, 1″ OD
3792-9	49″ Rear Cross Bar for Drum Rack
3792 11	49″ Front Cross Bar for Drum Rack

Figure 82. Diagram of a commercial, low gallonage assembly for tractor mounting.

Courtesy, Engine Parts Mfg. Co.

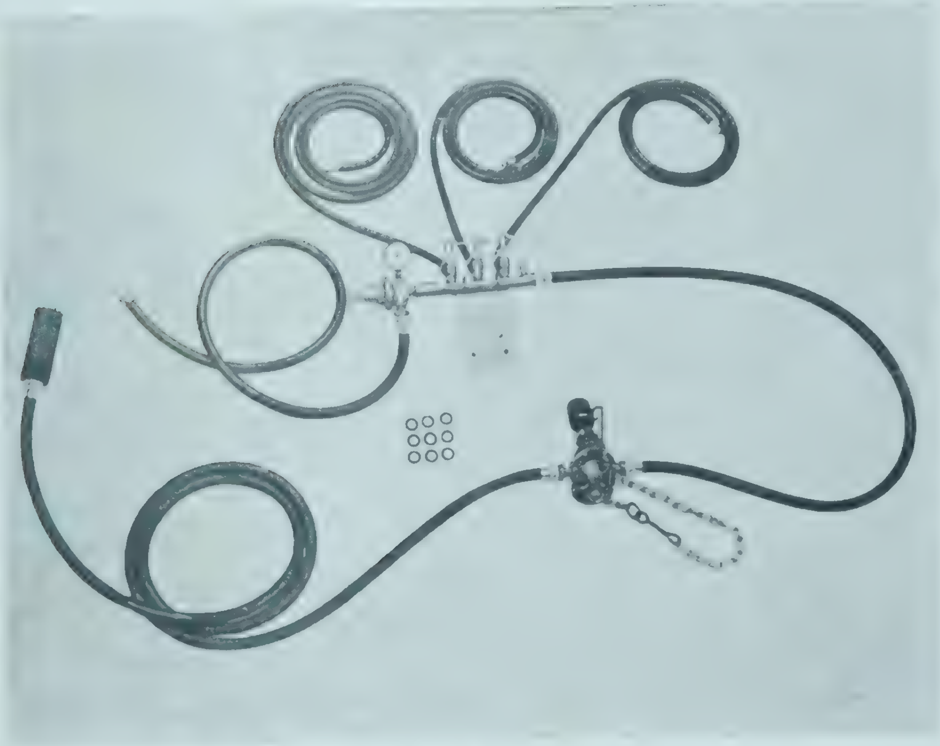
adjustment than is provided in the setting as shown, the standards may be removed from the collars and reversed, giving extremely low adjustments.

"The boom should be of 1-inch pipe for 2-row machines and 1¼-inch pipe for 4-row outfits. Row width will determine the length in either case. After the boom is cut to length both ends are capped. A ¼-inch hole is then drilled to accommodate the supply hose. This should be located slightly to one side of the end of the tank and on the top side of the boom. Over this hole is welded a ¼-inch pipe coupling to accommodate the supply hose from the pump. If the gauge is to be mounted in the boom itself, another hole and welded coupling will be necessary. On the lower side of the boom, holes are drilled to accommodate the nozzles and ¼-inch pipe couplings welded over them. These holes should be spaced along the boom at one-half the row width of the crop. This allows one nozzle to be directly over each row and one in each middle. One nozzle would be used per row for early spraying with the two side nozzles removed and pipe plugs installed in their place. As the plants grow in size the two side nozzles would be used with the center nozzle outlet plugged. Still later this plug would be removed, the nozzle reinstalled and spraying would be with three nozzles per row as shown.

"A simple front nozzle arrangement can be made by welding ⅝-inch set collars to the cultivator truss rods or frames directly over the row. If so desired, the set collar can be welded to a clamp for attaching to either the frame or truss rod. This allows adjustment of the nozzles for various row widths. The clamp must be made to fit the individual cultivator. One, two or three nozzles may be used per row as described above, the openings not in use being sealed with pipe plugs. The set collar allows adjustments to be made for height. This is a very simple and easy to fabricate arrangement but would not prove to be as satisfactory in large cotton as the adjustable boom type. The height of the cultivator frame from the ground will limit vertical adjustment in the upward position.

"When flame cultivators are used farmers may wish to utilize the framework of this machine as a boom mounting. The tank must be mounted on the front. The boom is made as has been described previously and is attached to the main pipe frame of the flame cultivator either by welded standards or clamps."

Most machines are 2-, 4-, 6-, and 8-row units, with 2- and 4-row outfits being the basic unit and boom extensions made available for



CAUTION: DO NOT RUN PUMP IF TANK OR DRUM IS DRY AS THIS WILL CAUSE RAPID WEAR AND MAY QUICKLY RUIN PUMP.

USE OF EXCESSIVELY ABRASIVE MIXTURES CAUSES RAPID WEAR AND FAILURE OF THE PUMP.

1. Fasten power take-off coupling to power take-off shaft of tractor removing steel bushing for 1 3/8 inch shafts.
2. Place pump shaft in coupling and tighten. Be sure the coupling clears the seal nut by at least 1/16 of an inch.
3. Fasten eyebolt of torque chain up through opening provided in pump casting. Fasten chain to some point on your right if you were sitting in tractor seat. Fasten to left if shaft turns counterclockwise.
4. Put the hose adapter fitting into the pump openings using sealing compound or shellac to insure leakproof fit. Attach long ½" hose to left side of pump. Place strainer on other end of the hose and place in Drum. This is the suction hose.
5. Fasten regulator and gauge unit to right fender beside driver or to some other convenient spot on sprayer or tractor. Use short ½" hose to couple the right side of pump to the regulator as shown in photo.
6. From the valves on the regulator nut fasten hoses to connect to the feeder openings on the booms. The remaining outlet on the regulator itself should be connected to a ½" hose that returns to the tank or drum for overflow.
7. If the shaft turns counterclockwise the hose connections on the pump should be reversed.

OPERATION

To start pump open valve to boom and turn regulator adjusting screw counterclockwise until loose. Make sure suction hose is immersed in water or spraying liquid and start pump. As soon as flow is smooth turn regulator screw clockwise until gauge shows desired pressure. Tighten locknuts on screw to prevent loosening while operating. You can now shut boom valve if desired.

MAINTENANCE

The pump will give best service if flushed with clean water after each use. It requires no lubrication other than the liquid running through it.

To clean filter:

1. When possible attach filter to any sprinkler hose and flush out with water.
2. Unscrew hose fitting from filter so felts may be removed. Wash them in strong soap and water: or, if tar substances are present, in gasoline or solvent. Reassemble.
3. In field emergencies, back flush with spray solution. To do this:
    1. Remove filter from intake hose and attach to end of overflow hose.
    2. Close valve to boom.
    3. With filter out of tank, dip intake hose into tank just below surface of liquid and run pump briefly for a short flush. Reassemble in original manner for further operation making sure felts are uniformly compressed.

Figure 83. Assembly instructions for a commercial manifold pump unit.

Courtesy, Engine Parts Mfg. Co.

the wider row widths. The nozzles on the boom, or the boom itself, should be adjustable from approximately 12 inches from the ground to 4½ feet.

COMMERCIAL LOW GALLONAGE MACHINES. In general, the low gallonage rigs made by reputable commercial concerns are superior to most home-made outfits. They are more expensive, but the difference in cost is not as great as one might expect after deducting for retail prices and for the time spent constructing the machine. Most sprayers cost 65 to 400 dollars if tractor-mounted and 350 to 700 dollars if trailer-mounted.

Several companies are now supplying spray kits, parts, and boom extensions to fit any type of tractor specified by the grower. Complete trailer and trailer-mounted rigs may also be procured.

Some booms are simply straight pipes with nozzles and plugs at 12-, 18-, and 20-inch intervals for broadcast spraying; or they may be equipped with nozzle drops and pendants for regulating height and nozzle direction. They are usually provided with a break on both sides to permit raising or angling on one side and for going through gaps and gates. A spring-loaded collision hinge is attached at the two breaks.

To protect the liquid line from strain, most booms consist of a steel outer tube (1 to 1½ inches) containing a ⅜ to ½ inch brass liquid tube. The spray control shut-off valves should be located near the driver's seat, handy for the operator, so that each boom section can be operated separately or simultaneously. The average 6-row boom is 18½ feet long.

Most tank drums are mounted to the rear of the tractor as a safety precaution. Drum racks may be obtained for one or for two drums. It is very disappointing that many tanks are subject to rust and corrosion which continually plagues the operator with plugged screens and clogged nozzles, especially after the first season. This is not necessary in view of the fact that tanks may now be coated with materials that prevent this difficulty.

Figures 82, 83, and 85 illustrate the construction and attachment of low gallonage equipment such as the "Yellow Devil." Figure 86 shows 4 different types of pumps. Figure 87 shows one type of nozzle setting attachment and "Yellow Devil" calibration accessories.

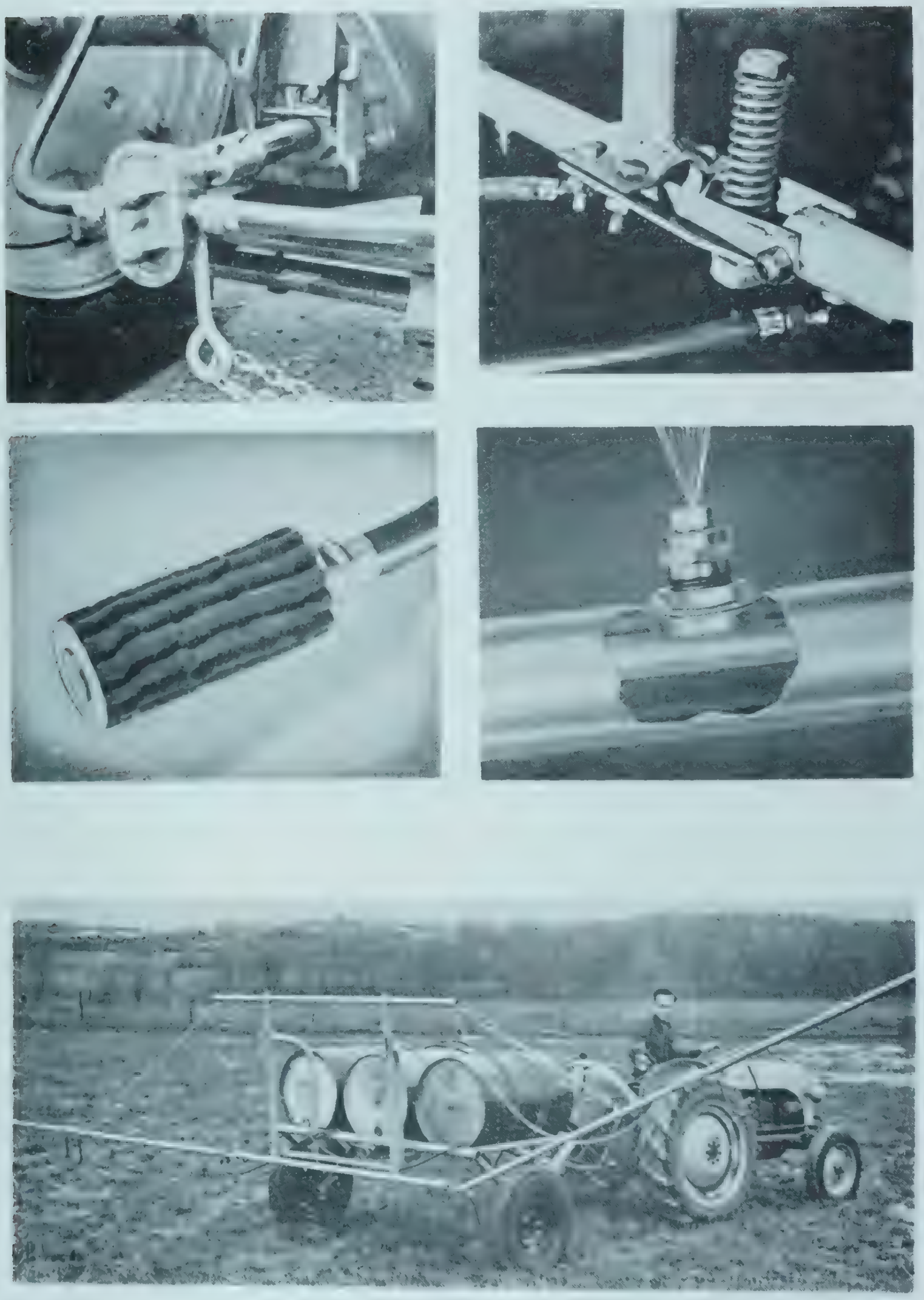


Figure 84. Parts for "Yellow Devil" sprayer: (left to right, and top to bottom)
Chrome plated bronze gear pump with stainless steel shaft running in graphite bearings that does not require oil or grease.
Teejet safety hinge and spring
Felt filter to clean, squeeze and wash
Teejet nozzle
Booms can be angled at either end from the seat.

Courtesy, Engine Parts Mfg. Co.

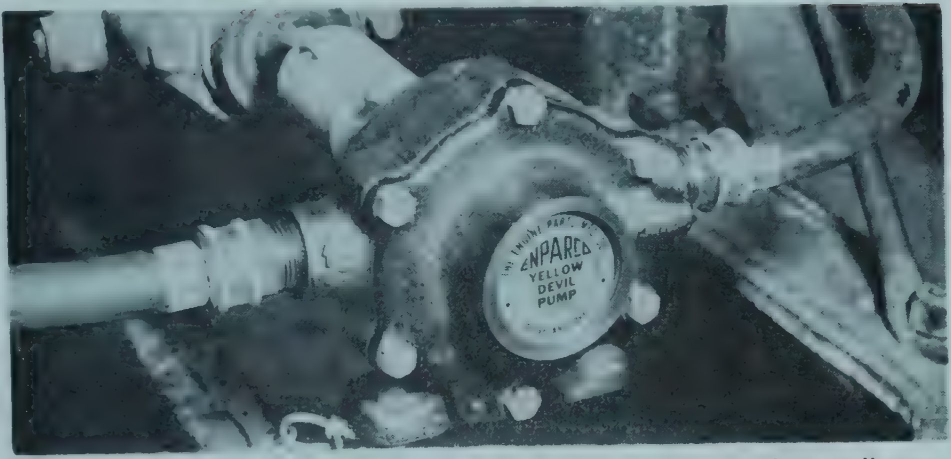

ENPARCO
YELLOW
DEVIL
PUMP

Figure 85 Tractor mounted direct drive rotary pump for low gallonage

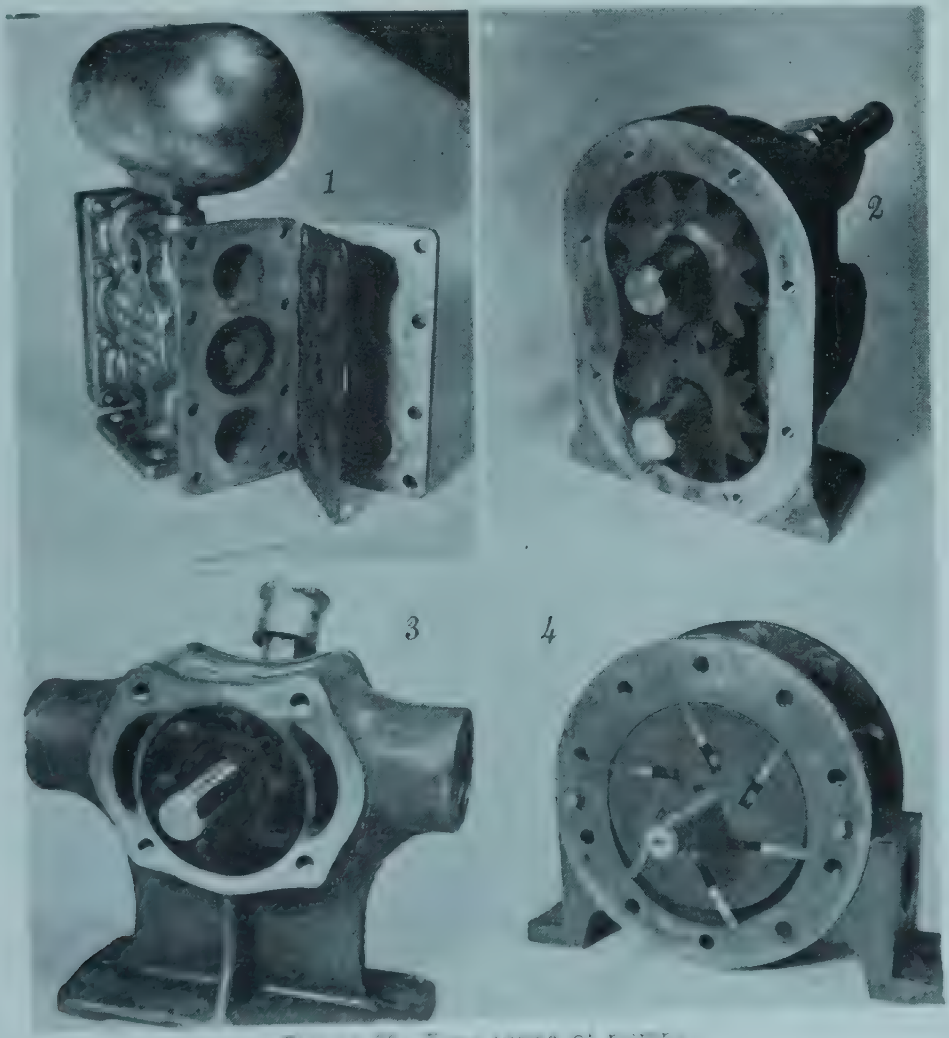


Figure 86 Four types of pumps.

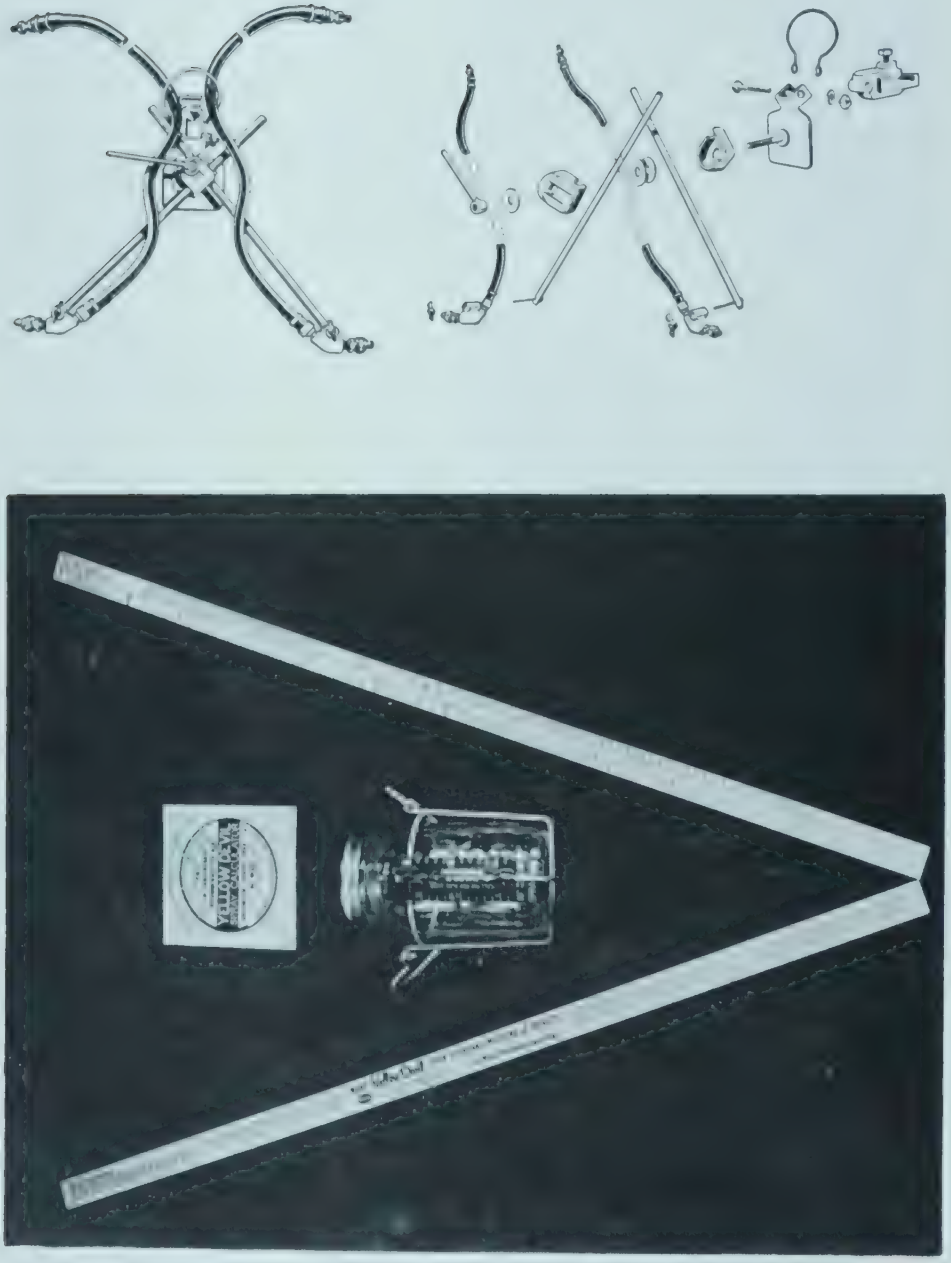


Figure 87. Accessories: Top: Nozzle drops and parts: Bottom: Calibration jar, gauge to show liquid level in tanks, and chart for reading row crop acreage.

Courtesy, Engine Parts Mfg. Co.

BOOMLESS NOZZLE CLUSTER. Some companies are now featuring the use of a single nozzle cluster of 1 to 5 slot-type orifices in place of a long boom of many nozzles (Figures 88 and 89). This system has both advantages and disadvantages. It is simple, cheaper to install, and will apply any kind of spray mixture without clogging. Disadvantages are: more uneven coverage, coarser atomization, more affected by wind, and the need for greater pump capacity and a higher gallonage per unit area. The single nozzle cluster, however, seems to have a future in the application of pre-emergence chemicals and fertilizer or nutrient sprays, and for spraying fence rows and roadsides.

APPLICATION TO VEGETABLE CROPS FOR PEST CONTROL. Low gallonage, non-blower sprayers may be used for applying semi-concentrated mixtures of 4x to 6x concentration where fungicides and wettable powders are included in them. Some active forms such as flea beetles, leaf hoppers, and potato beetles can be controlled with 10x concentration and many of the nutrient and fertilizer sprays are effective at the 10x concentration. The use of low gallonage equipment for potato disease and insect control is well described by Peikert and Bonde* as follows:

Equipment Used in Tests. "In these tests comparisons were made between pull-type, low-gallonage sprayers which applied 25 to 30 gallons per acre at a pressure of 75 to 80 p.s.i. and a conventional high-pressure sprayer which applied 100 to 200 gallons per acre at 400 p.s.i. Travel speed in all cases was four miles per hour.

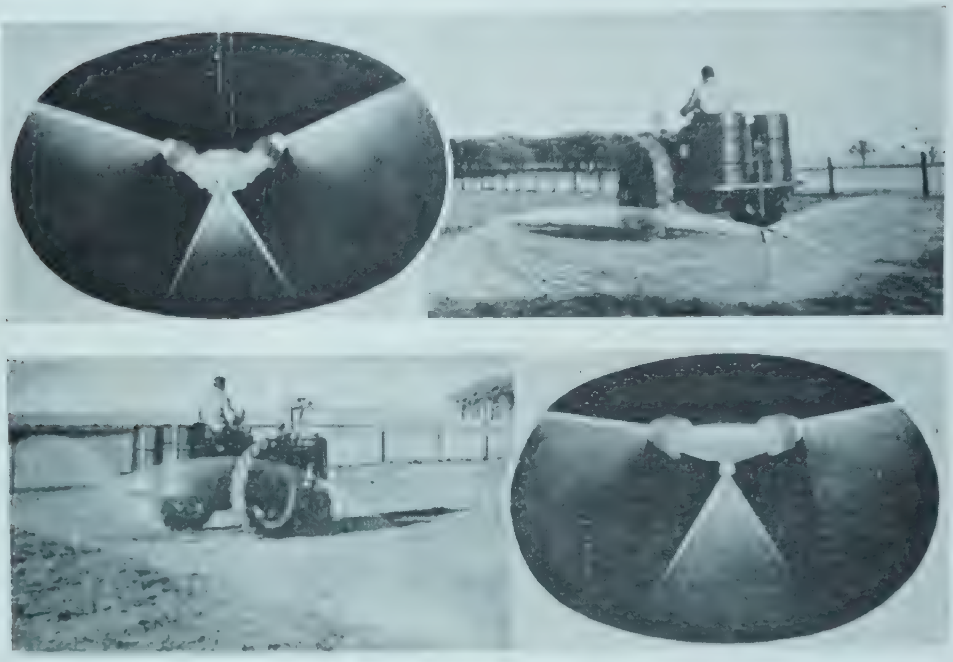
"Two low-pressure machines of similar design were used during the four years of tests; both were trailing types with 8-row booms and one-cylinder engines.

"For the 1950-1952 seasons the low gallonage test sprayer was a Hudson Peerless. It had a pump capacity of five g.p.m. and was driven by a 2½ h.p. engine. The operating pressure was kept as nearly as possible to between 70 and 80 pounds per square inch. The machine had a 100 gallon tank, although most of the sprayers used in the area had 150 gallon capacity.

"In the 1953 tests a GP Model Myers sprayer was used. It had a pump capacity of seven g.p.m. and was driven by a four h.p. engine. The operating pressure was maintained at 80 p.s.i. This particular machine had a 100 gallon tank; however, it is also obtainable with a 200 gallon tank.

---

*Peikert, F. W. and Reiner Bonde. Potato disease and insect control with low gallonage sprayers. Maine Exp. Sta. Bull. 527. 1954.



Boomless sprayer with triple-orifice nozzle cluster

Courtesy, Hanson Chemicals and Equipment Co.

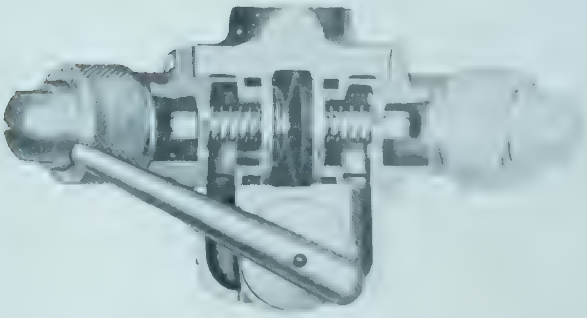


Figure 88. A boomless field, pasture and row crop sprayer that automatically takes advantage of cross winds to permit spraying up to a 40-foot swath has been introduced by Hanson Equipment Company. Illustrations of the equipment appear on these facing pages

Cross winds that stop ordinary sprayers are made to aid the new sprayer by an automatic valve. As the sprayer goes down field, the nozzle facing the wind is shut off. The open nozzle sprays with the wind. When the sprayer reaches the end of its run, a simple flip of the control valve handle turns the spray off. After turning to return down field, the operator flips the control valve handle to turn the sprayer on again. But the automatic valve directs the spray to the other nozzle so that automatically the wind again aids spraying. When winds are blowing in the sme direction as the sprayer travels, all nozzles can be opened to get a swath up to 68 feet wide.

Boomless sprayer operating to one side.

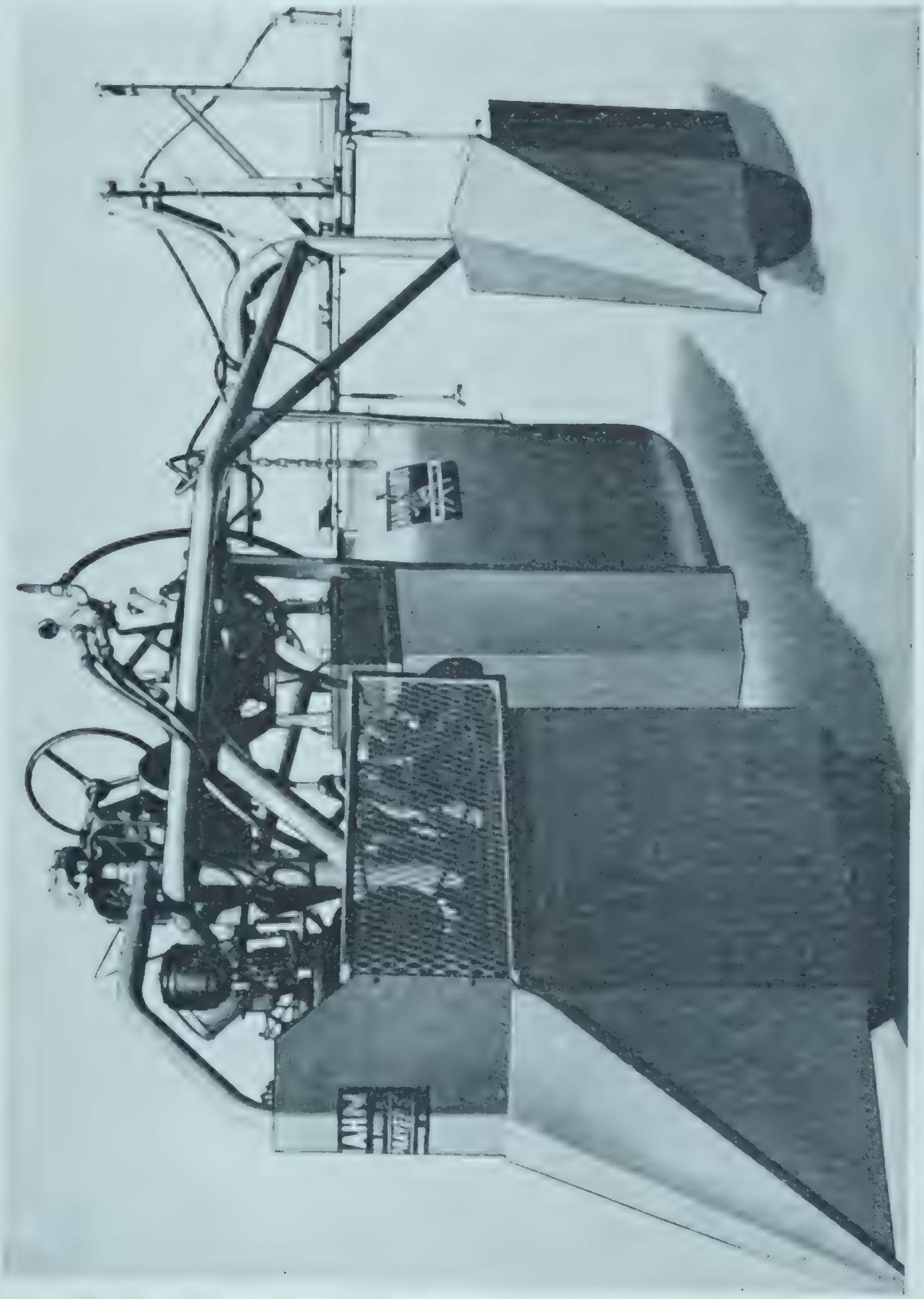


Figure 89 Hahn high-clearance, low gallonage sprayer for applying insecticides and chemical defoliants to cotton.

Courtesy, Hahn Co., Inc.

"Both low-pressure machines had three nozzles per row. The longest drop pipes possible were used and were arranged so that each row had a nozzle directly above it and a nozzle on each side.

"In 1953 another series of plots were sprayed with an 8-row, tractor-mounted unit. This sprayer had a power-take-off pump with about five g.p.m. capacity at 80 p.s.i., a 50 gallon tractor-mounted tank and the same boom as that used on the pull-type Myers GP sprayer. This boom was mounted on the front of the tractor.

"Comparative tests were made with the low-pressure sprayer using long drop pipes, short drop pipes, and a brush-type boom [which proved that the long drop pipes were superior to the other two arrangements].*

"The long drop pipes were flexible pendants 26 inches long, each with a hose supplying two nozzles which were set so as to cover one side of two rows. Each short drop was made from two pipe pendants 10 inches long with a nozzle directed to the side of the row. The brush boom had all three nozzles per row at the boom level without using any drop pipes. Comparisons were made both on the coverage of the spray materials as indicated by leaf prints and on the control obtained on aphids."

Advantages of Low-Gallonage Sprayers

The advantages of low-gallonage, high-concentration sprayers over the conventional machines for truck crops are:

1. Lower initial cost. At present it is about one-half that of high pressure sprayers.

2. At least three-fourths less water is used. This may be an important factor where water is limited or must be hauled a considerable distance to the field.

3. Lighter in weight. Operated under lower pressure and having a smaller tank, high concentrate sprayers can be built considerably lighter throughout. The result should be less packing of the soil when compared to a heavier conventional pull-type machine carrying larger loads of water.

4. Less power required per acre in applying spray materials. With its lower operating pressure, it requires less power for pumping, whether driven from a separate engine or from power-take-off. The power needed to pull the lighter weight machine through the fields is also less.

---

* Author's insert.

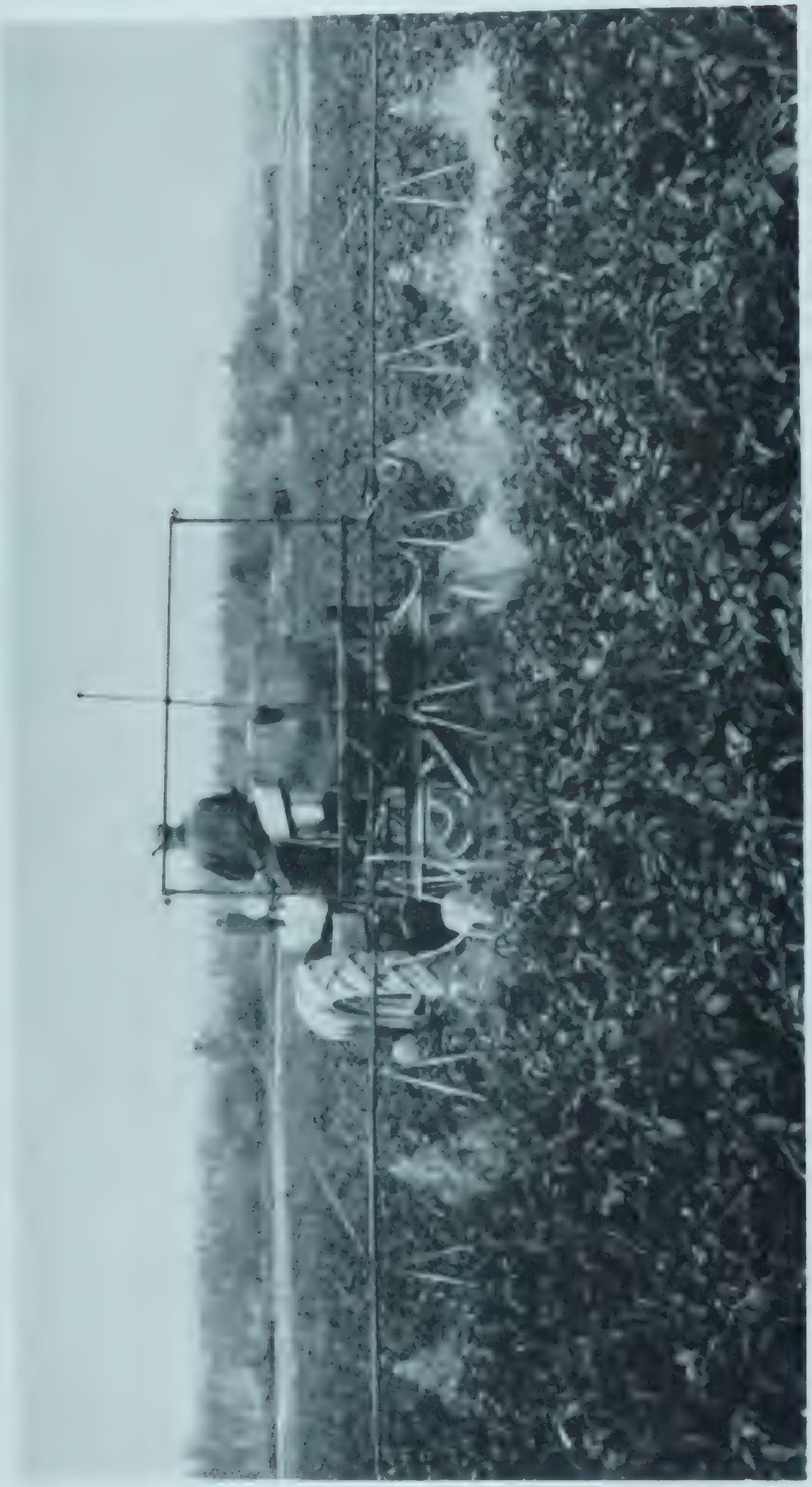


Figure 90. An 8-row low gallonage tractor mounted rig treating potatoes with recommended long drop pipes.

Peikert and Bonde, 1950.

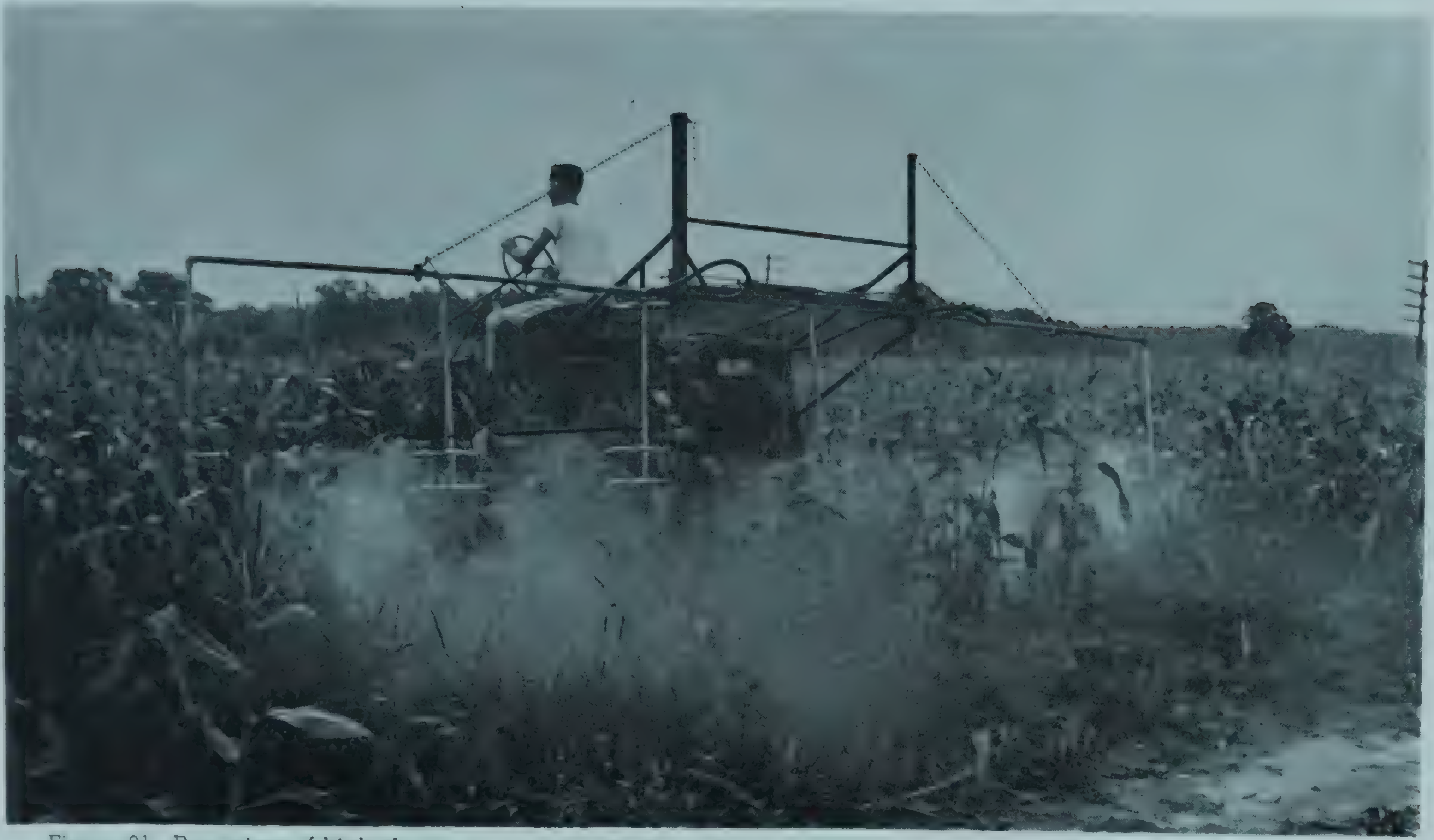


Figure 91. Rear view of high-clearance sprayer with 6-row boom designed for coverage of ear zone of sweet corn.

Black, Ditman, and Burkhardt, 1954.

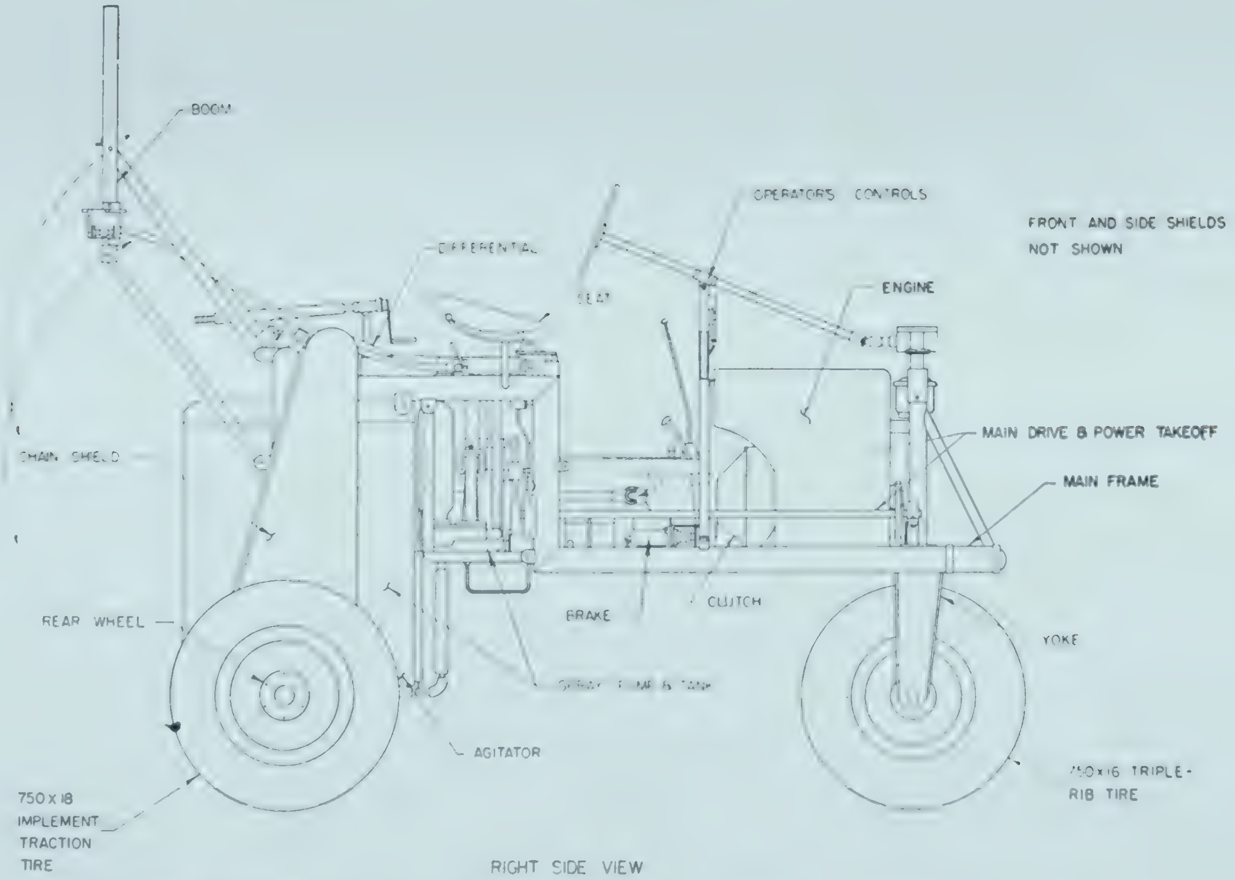

BOOM
DIFFERENTIAL
SEAT
OPERATOR'S CONTROLS
FRONT AND SIDE SHIELDS NOT SHOWN
ENGINE
MAIN DRIVE & POWER TAKEOFF
MAIN FRAME
CHAIN SHIELD
REAR WHEEL
BRAKE
CLUTCH
YOKE
SPRAY PUMP & TANK
AGITATOR
750 X 18 IMPLEMENT TRACTION TIRE
750 x 16 TRIPLE-RIB TIRE
RIGHT SIDE VIEW

Figure 92 Assembly drawing of high-clearance self-propelled sprayer for sweet corn

Black, Ditman, and Burkhardt, 1954.

WEED CONTROL EQUIPMENT. Weed control equipment for applying hormone type sprays in low gallonages to foliage is similar to that described for cotton. For pastures, small grain fields, and general broadcast application the straight boom arrangement is used without drop nozzles. Fan spray nozzles as Teejet 650067, are usually spaced 18 to 24 inches apart along the boom at a distance of 8 to 18 inches from the growth (averaging 10 inches) depending on wind conditions and the distance of throw of the spray. Usually 4 to 10 gallons are dispersed per acre, requiring nozzles delivering 3 to 10 gallons per hour at 30 to 70 p.s.i. In the aggregate, vast acreages are being treated with this equipment using 4 ounces to 3 pounds of 2,4-D acid per acre, with the usual dosage being between eight and 24 ounces of the acid, depending on degree of sensitivity of the plants. The acid is applied in oil or is emulsified in water as the carrier. A modified row or drop nozzle type of boom is sometimes used for treating corn for weed control to get the spray down below the corn foliage onto the weeds growing at or near the ground. After field corn has reached considerable height, however, it is not feasible to get through with ordinary ground equipment.

EQUIPMENT FOR APPLYING INSECTICIDES TO TURF, PASTURES, CLOVER, AND FIELDS OF SMALL GRAIN. Low gallonage machines for treating turf and the above crops are similar to the equipment used for weed control and insecticide spraying of cotton and most other field crops. The straight, boom equipment is applicable to most field crops and pastures. This is a tremendously important phase of agriculture.

Information on spray materials and formulations for use in low gallonage rigs on these crops is given in the section on spray chemicals and formulations.

For lawn mowers, one type of small low gallonage apparatus consists of a small detachable tank, ¼-inch gear pump costing 10 to 12 dollars, shut-off valve, and a short pipe of about two feet for two, 2 to 4 g.p.m. atomizing nozzles at 20 to 40 p.s.i. A separate attachment can be supplied for spraying shrubbery up to 12 feet in height, consisting of two 3-foot lengths of light extension rods attached to 10 to 12 feet of ¼-inch hose. The above apparatus cannot handle wettable powders, but can apply water solutions and emulsions of insecticides, nutrients, and foliage fertilizers such as Fer-Mel, Rapid-Gro, potassium nitrate, Nu Green, etc.

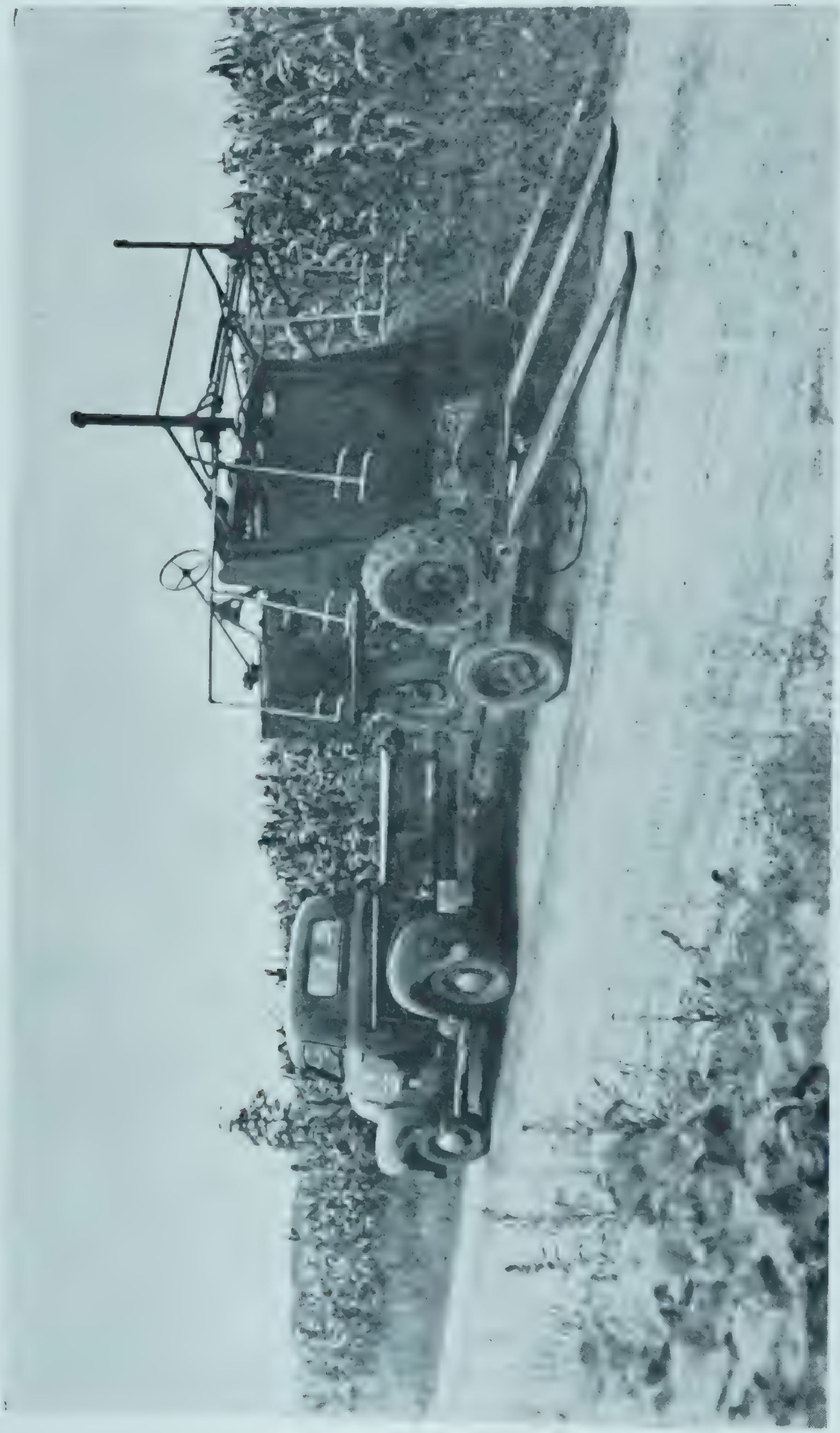


Figure 93. Specially designed low-bed trailer for transporting sprayer from field to field.

Black, Ditman, and Burkhardt, 1954.

APPLICATION OF NUTRIENTS AND FERTILIZERS AS SPRAYS WITH LOW GALLONAGE RIGS. The low gallonage machines just described for field crops, cotton insecticides, and herbicides are well suited for applying the above materials to vegetables, pastures, clover, grain fields, and field crops in general. The straight boom equipment appears to be sufficient for most nutrients since they do not require quite as fine atomization or as complete coverage as do the fungicides.

The use of nutrients and fertilizers in concentrated sprays is a potentially big and important new field about which much is yet to be learned regarding the proper chemicals, formulations, dosages, concentration, gallonage per acre, timing, and number of applications.

Some information on the above is given in the chapter on spray chemicals and formulations (chapter 5). In many cases, the nutrients or fertilizers can be formulated in the same mixture with insecticides and fungicides. Usually soluble nutrients can be selected to give the concentration desired, but some granular materials have to be ground finer to go through the pumps and nozzles. Also, the use of materials that cause plant injury must be avoided.

A High-Clearance Self-Propelled Sprayer for Sweet Corn

UNDER the Federal Food, Drug and Cosmetics Act, no insect contamination is tolerated in canned or frozen corn. In view of present infestation levels of such insects as the European corn borer (*Pyrausta nubilalis* Hbn.), corn earworm (*Heliothis zea* Boddie), fall armyworm (*Laphygma frugiperda* J. E. Smith), and Japanese beetle (*Popillia japonica* Newm.), canners may be greatly concerned over the possibility of losing large quantities of canned corn. For effective large scale insecticide application without stalk breakage, specially designed high-clearance self-propelled equipment is essential. Boom and nozzle design must, with a minimum of waste, direct the insecticide to areas of the plant where it can give the best results. Equipment must be safe and stable and have adequate power and traction (Figures 91, 92, and 93).

Most of the information on high-clearance corn insecticide equipment has been taken from two publications that describe the equipment and method in detail (Blanchard, Douglas, Wene, and Wooten, 1951; Black, Ditman, and Burkhardt, 1954).

SOME HIGH-CLEARANCE SPRAYER SPECIFICATIONS

From Black, Ditman, and Burkhardt, 1954, p. 8-9.

General Description: Tricycle type, two rear drive wheels, single-front-wheel steering, single engine for traction and spray pump, tubular frame, rear frame and wheels straddle two rows, clearance over rows 60 inches, wheel base 88 inches, tread of rear wheels 84 inches.

Center-of-Gravity Location: Tank empty and without driver, 33.0 inches forward of rear axle and 39.2 inches above ground level. Tank full and 155-pound driver, 18.1 inches forward of rear axle and 42.7 inches above ground level.

Weight: Tank empty and without driver, 2,280 pounds. Tank full and with 155-pound driver, 3,676 pounds.

Engine: Two-cylinder, air-cooled power unit, rated 13 h.p. at 2,400 r.p.m.

Clutch: Automotive-type, spring-loaded, 8½ inches.

Transmission: Three forward speeds, one reverse, maximum road speed 11 m.p.h.

Differential: Automotive-type, converted.

Tires: Front, 7.50 x 16 triple-rib; rear, 7.50 x 18 implement-traction.

Brakes: Hydraulic, automotive-type, on rear wheels, foot-pedal control.

Power Takeoff: From front of engine, belt-driven shaft, belt-tightening-type clutch.

Pump: Duplex, capacity 7 g.p.m. at 70 r.p.m. and up to 400 p.s.i.

High-Pressure Regulator: Unloading type, range 0-400 p.s.i. adjustable.

Low-Pressure Regulator: Diaphragm relief-type, range 0-125 p.s.i., adjustable.

Tank: Capacity 150 gallons, width 23 inches, length 44 inches, depth 38 inches, with semicylindrical bottom; material 18-gauge galvanized sheet iron, clearance 16½ inches above ground.

Agitator: Four two-bladed paddles, 3 inches wide and 4-inch tip radius, driven by chain from pump, 120 r.p.m.

Strainers: Tank-filler strainer of 20 mesh screen; suction-line strainer of 50 mesh; and pressure line-strainer of 50 mesh.

Spray Boom: Six-row coverage, vertical adjustment by parallel links operated by screw crank from driver's seat, boom side extensions raised by ropes and pulleys to vertical for turning or transporting; spring loaded hinges for either forward or rear folding, self turning to operating position.

BOOM ON EXPERIMENTAL MACHINE. The boom used by Black, Ditman, and Burkhardt (1954, pp. 2 and 5) can be adjusted vertically to a maximum height of 80 inches by means of parallel links operated by a screw crank from the driver's seat. They describe the unit as follows: "Spring-loaded hinges permit either forward or rear folding of the boom extensions and serve as safety devices if obstacles are encountered. The boom extensions may also be raised to a vertical position when the sprayer is to be turned or transported. Rigid drop feed lines 28 to 30 inches long are placed on the boom at 42-inch intervals. This spacing permits suspending the feed lines between the corn rows at intervals the same as the standard row intervals. Where row spacing is less than 42 inches, the operator angles the boom extensions forward. Four narrow-angle flat spray nozzles are used per row. All spray-line piping with the exception of rubber hose connections is galvanized. The nozzles are tipped with stainless steel. The nozzle pattern was designed primarily for corn earworm control as the limiting factor. The earworm feeds in the ear under the protection of the husks.

"The upper nozzles on the boom drops are about five inches above the lower, and all nozzles are about seven inches from the feed line so as to apply a fairly narrow band. The nozzles are directed downward at an angle of approximately 35 degrees, so that the spray is driven down into the ear and plant. The upper nozzles are directed slightly forward and the lower nozzles slightly backward.

"The operator's seat is situated so that he has an unobstructed view of the boom and the row. All controls are within easy reach. A direct-driven speedometer is provided to aid in maintaining a constant rate of travel, which is an important factor in maintaining a correct rate of insecticide application. In some cases it was necessary to fold one of the boom extensions while turning. The row spacings averaged 40 inches. By angling the boom extensions forward a good spray coverage was obtained on 36-inch rows. On the average, a speed of four miles per hour was maintained in spraying except on large level fields where it was increased to 4½ miles. To deliver a 6x concentration of 30 gallons per acre to 40-inch rows with four nozzles at four m.p.h. travel would require a delivery of 12.1 gallons per nozzle per hour. Operating pressures may range between 70 and 120 p.s.i."

SOME FACTORS IN OPERATING EFFICIENCY. Black, Ditman, and Burkhardt (1954, pp. 9-10) have shown that:

"In the commercial-scale spraying most fields of each canner were within a 5-mile radius of the canning plant but the timing order of spray application was such that it was necessary to travel 2 to 3 miles on an average and in some cases as far as 15 miles between two fields treated consecutively. As the sprayer's maximum road speed was restricted to 11 miles per hour for safety reasons, it was more practical to use a specially constructed low-bed trailer equipped for fast loading (Figure 93). The sprayer was quickly and easily tied down to the trailer with load binders. This trailer was used during both seasons, and the amount of time thus saved was appreciable. It was found that a spraying crew of two men was adequate—one man to operate the sprayer and one to keep spray material ready for quick refilling.

"During the second season, an effort was made to reduce the time required by the actual spraying operation. A 900-gallon tank was procured and mounted on a platform truck. An agitator was installed for mixing and maintaining the spray material. A small gasoline engine powered the agitator, and a 50-gallon-per-minute centrifugal pump was used for transferring the insecticide to the sprayer in the field. This pump was so connected that, by manipulating valves, materials could be moved into or out of the mixing tank at high rates. Water for refilling the nurse tank was usually available from a water tower at the canning plant. In an emergency, it could be pumped in. The insecticide used in the second year came as a proprietary product, containing mineral oil and DDT emulsion, which was diluted at the rate of one part stock to nine parts water.

"By using one drum of the stock, a load of 540 gallons was made at one time. One man, using the nurse-truck pump for moving the stock from drum to tank, could make the transfer rapidly from ground level, with no lifting. Use of the nurse truck containing premixed spray material reduced from nine to about four minutes the time required for a complete refill in the field. It also eliminated the necessity of calculating fractional sprayer loads in the field, a problem that otherwise arises whenever the sprayer tank must be replenished without having been completely emptied.

"Several fields of only 3 to 5 acres each were treated during the first season. The high ratio of preparation-for-spraying time to actual spraying time in these cases makes the economic feasibility of treating such small fields debatable. If a canner's entire acreage were made up of small fields such as these, the maximum acreage treated per day would not be more than 30. On the other hand, where fields average 30 to 40 acres it would be possible to cover between 60 and 70 acres per day.

"Darkness restricts the working day but the sprayer can be equipped with lights for night operation.

COMMERCIAL OPERATION COSTS. "The spray formulation used in these operations, as in all the other testing, was a mixture of 30 per cent DDT emulsion, white mineral oil, and water, following closely the recommendations of Blanchard.* This was applied at a per-acre rate of 30 to 35 gallons where only one treatment was given and 26 to 28 gallons where two treatments were given.

---

* **Blanchard, R. A., Douglas, W. A., Wene, G. P., and Wooten, O. B.** DDT Sprays for Control of the Corn Earworm and the Budworm in Sweet Corn. U.S. Bur. Ent. and Plant Quar. E-780. (Revised) 1951.

The original cost of the sprayers is to be written off over a 5-year period.

"The first canner furnished all labor, equipment, spray material, and fuel and kept an accurate record of expenditures. He bought white mineral oil at $0.50 per gallon and 30 per cent DDT emulsion at $2.00 per gallon. The treated area totaled 735 acres. A single application at the rate of 34.6 gallons per acre was given to 487 acres, and two applications at the rate of 26.3 gallons per acre each were given to 248 acres."

The canner summarized his costs for spraying as follows:

Overall cost:

Depreciation of equipment*	$ 756.50
Truck hire	210.50
Fuel	61.30
Labor	765.84
Insecticide	2,737.00
Total	$4,531.14

"Cost broken down on basis of acreage and yield:

Average cost per acre application	$4.60
Average insecticide cost per acre application	2.78
Labor and overhead cost per acre application	1.82
Average cost of operation per ton of corn	1.54"

OTHER TYPES OF MACHINES FOR CORN EARWORMS. The information below on small power and hand equipment for corn was abstracted from the findings of various workers. One of the best and most inclusive papers on this subject is by Blanchard, Douglas, Wene, and Wooten (1951).

Paint-Spray Machine. One type of equipment used for applying sprays to individual ears was a small paint-spray machine with a compressor run by a gasoline motor. This outfit, operated at a pressure of 30 p.s.i. breaks up the spray well and drives it into the silk mass. The equipment used in our tests had a 1-quart liquid container, but it might be feasible to use a machine having a large liquid container from which several guns are operated at the same time. Some means of agitating the spray, such as a pipe to conduct compressed air from the compressor to the bottom of the spray tank, is necessary where an emulsion containing mineral oil is used.

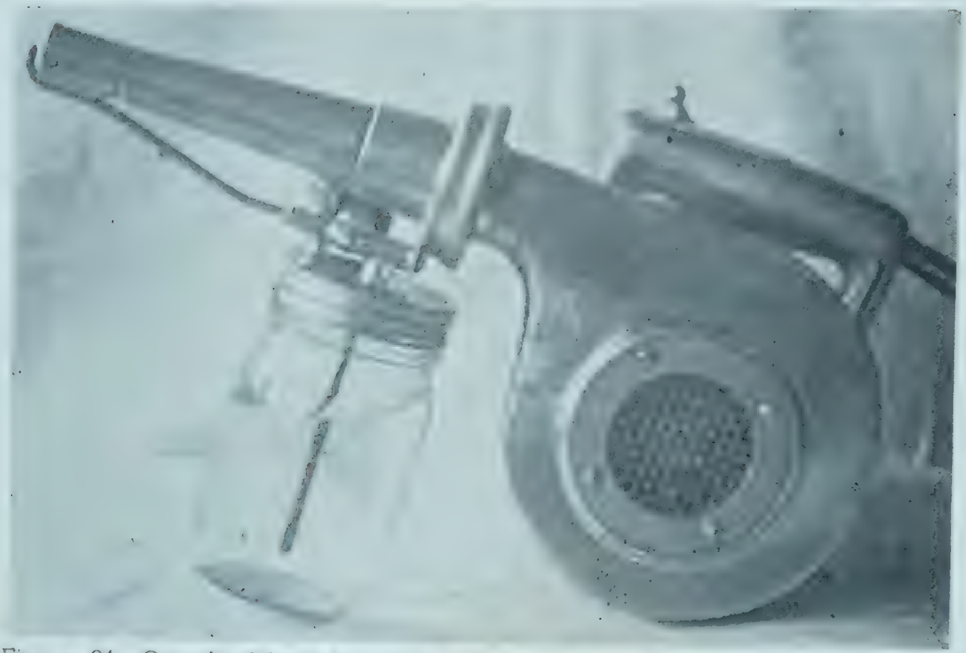


Figure 94. One third hp electric mist blower with screw-top for jars of one to four pints capacity, for indoor, greenhouse and garden treatments. Side view. Weight: 12 lbs.
Potts, Garman, Friend, and Spencer, 1950.

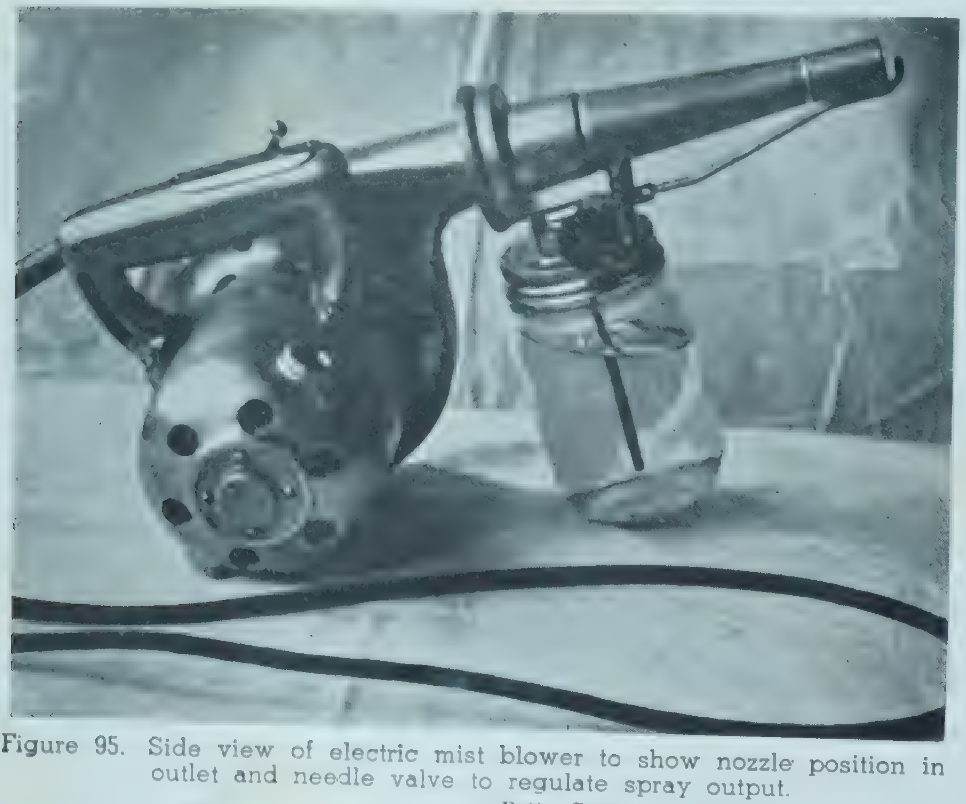


Figure 95. Side view of electric mist blower to show nozzle position in outlet and needle valve to regulate spray output.
Potts, Garman, Friend, and Spencer, 1950.

Power Sprayer with Nozzles for Hand Application. Both oil solutions and emulsions have been successfully applied to the individual ears with nozzles attached to hoses on a power sprayer. Each nozzle was equipped with a shut-off valve operated by hand. The spray outfit was mounted on two automobile wheels and was pulled by a mule between two rows of corn. A boom mounted above the corn had outlets for eight 20-foot hoses spaced the same distance apart as the corn rows, so that eight men could spray the ears in eight rows as the machine was pulled through the field. The men walked ahead of the machine, which was operated at a speed slow enough to allow them to spray each ear. The sprayer was operated at a pressure of 100 p.s.i. About 30 acres per day were treated in this manner.

A nozzle giving a very fine hollow cone of spray should be used for the hand applications. The angle formed by the cone of spray should not be wider than 50 degrees at 100 pounds' pressure. Otherwise, it is difficult to get proper coverage of the silks and ear tips. The nozzle should be held 3 or 4 inches above the ear tips and care taken to spray the entire silk and not just one side of the ear. Nozzles suitable for use with a power sprayer are manufactured by several spray-equipment companies, but extreme care should be used in selecting one that does not put out too large a volume of spray or too large droplets. Nozzles with capacities at 100 pounds' pressure of 1½ gallons per hour where the oil solution was used and 2½ gallons where the emulsion was used were found satisfactory. The nozzle assembly should be equipped with a lever-type shut-off valve that is easy to operate with one hand and has a positive cut-off. The same specifications also apply to the type of paint-spray gun selected, if that method of application is used. These sprays are not recommended for application by machines with fixed nozzles because of cost of the spray and the difficulty of getting good control with only one application.

Formulations for Single Hand Application to Individual Ears. A solution containing 1½ pounds of technical DDT in 25 gallons of white mineral oil of 65 to 95 seconds Saybolt viscosity can be applied to individual ears with knapsack sprayers or by men operating nozzles attached to a power sprayer, or with a paint-spray gun. *This solution should not be applied until after the ears have been fertilized,*

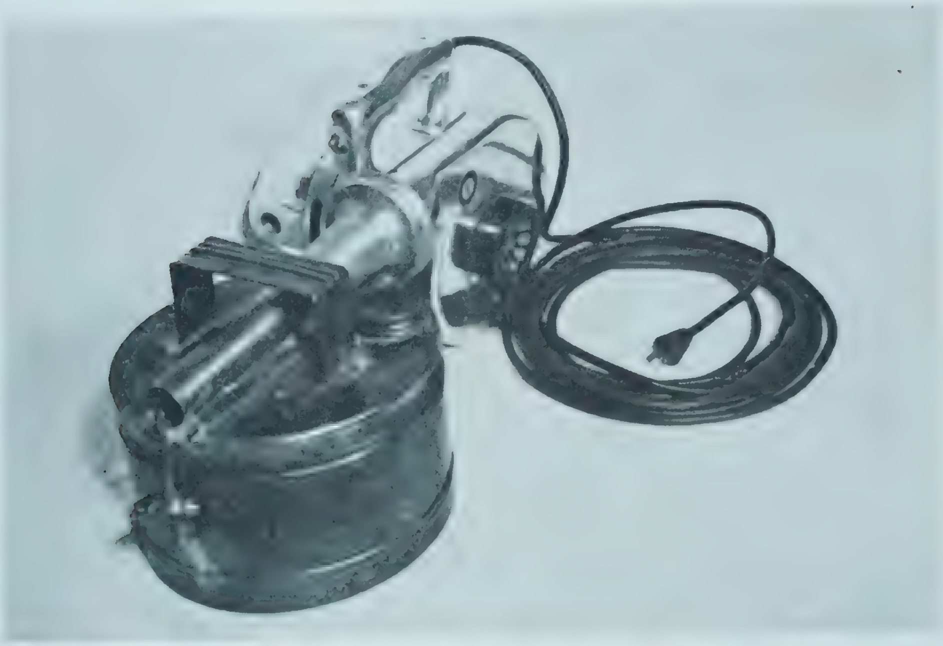


Figure 96. Redesigned commercial electric unit, modified for spraying concentrates by S. F. Potts and R. A. Spencer.

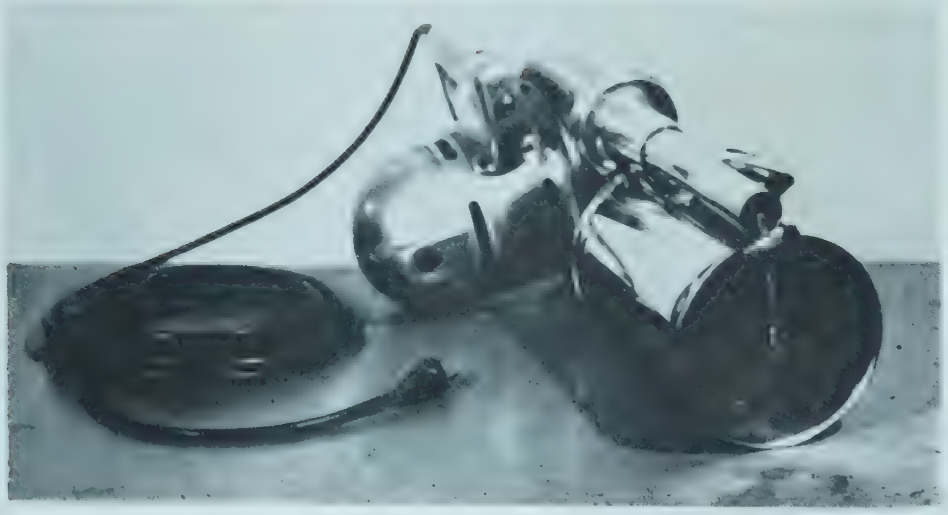


Figure 97. Redesigned commercial electric blower by S. F. Potts and R. A. Spencer. A new outlet, round tank with large filler opening and non-clog finely atomizing nozzle has been added

i.e., not until the silks have wilted and begun to turn brown at the outer ends.

An emulsion made from three quarts of factory prepared 25-percent DDT emulsifiable concentrate plus six gallons of the above-described white mineral oil diluted to 25 gallons with water can also be applied in this manner.* The oil and DDT concentrate are mixed together and then stirred into the water until a uniform milky-white liquid is formed. If sufficient agitation is provided by the spray machine, the oil and the DDT can be poured directly into the required amount of water in the spray tank. This emulsion should be applied as soon as 90 to 100 percent of the ears are in silk. A single application made at that time will not injure the ears.

Not more than ¼ teaspoonful of the oil solution or ½ teaspoonful of the emulsion should be applied per ear. Only one application should be made to each ear. The oil solution penetrates the ears better than the emulsion, and may give slightly better control of the worms, but will prevent the filling out of kernels at the ear tips. Although the emulsion gives a somewhat lower kill of the worms, the ears will fill out better at the tips. Either formulation will give good control if applied as recommended.

Higher concentration and lower volumes of spray mixture may be used for other corn insects when earworm control is not included in the treatment.

SOIL APPLICATIONS FOR INSECT PEST CONTROL. A low gallonage farm spray rig can be used to apply the insecticide (aldrin, DDT, dieldrin, heptachlor, chlordane, etc.) broadcast on top of ground to be cultivated. This may mean an extra trip over the field unless spraying and disking are combined. To prevent possible loss of the insecticide by evaporation and deterioration, disking should be done soon after spray application. This is particularly true for corn rootworm control. Cutworm sprays applied after the crop is up should be left undisturbed on the ground.

A low gallonage planter-mounted sprayer can be used to apply the insecticide or fungicide as a narrow band of five to seven inches wide over the trench just behind the planter shoe with one nozzle per row. Two to four gallons of mixture per acre is enough. This is an effective method.

---

* Emulsifiable concentrates containing 30 to 34 percent of DDT are also on the market. Five pints of the 30 percent concentrate or 4½ pints of the 34 percent concentrate should be used in 25 gallons of the spray. The amount of oil remains the same

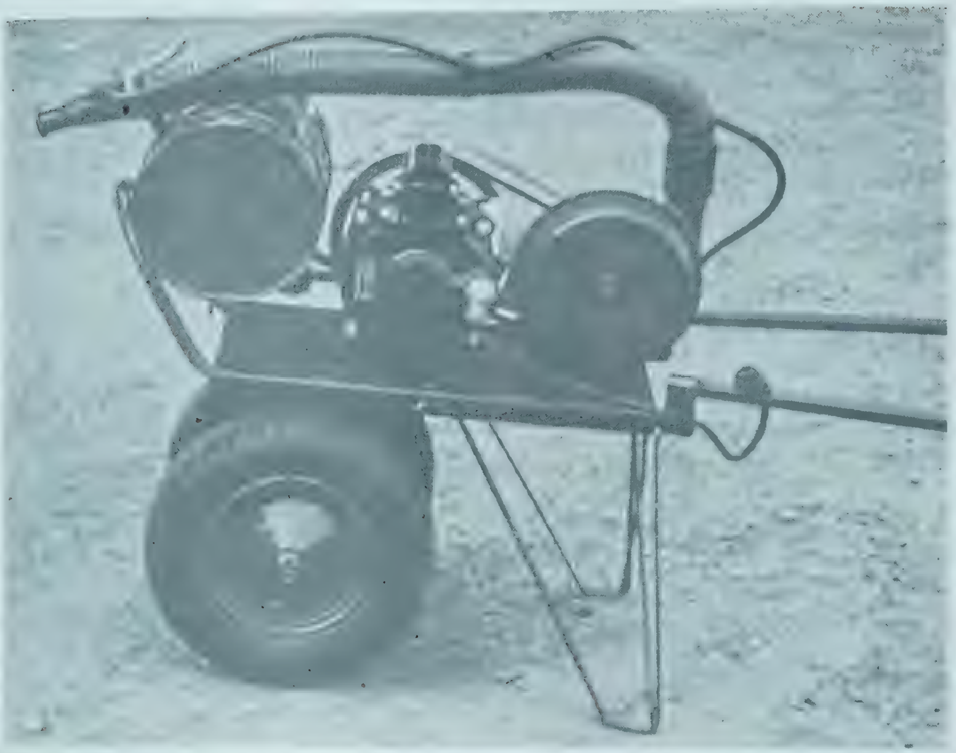


Figure 98. Side view of wheelbarrow mounted mist blower powered with an electric motor, flexible air hose and hand shut-off near nozzle.

Potts, Garman, Friend, and Spencer, 1950.

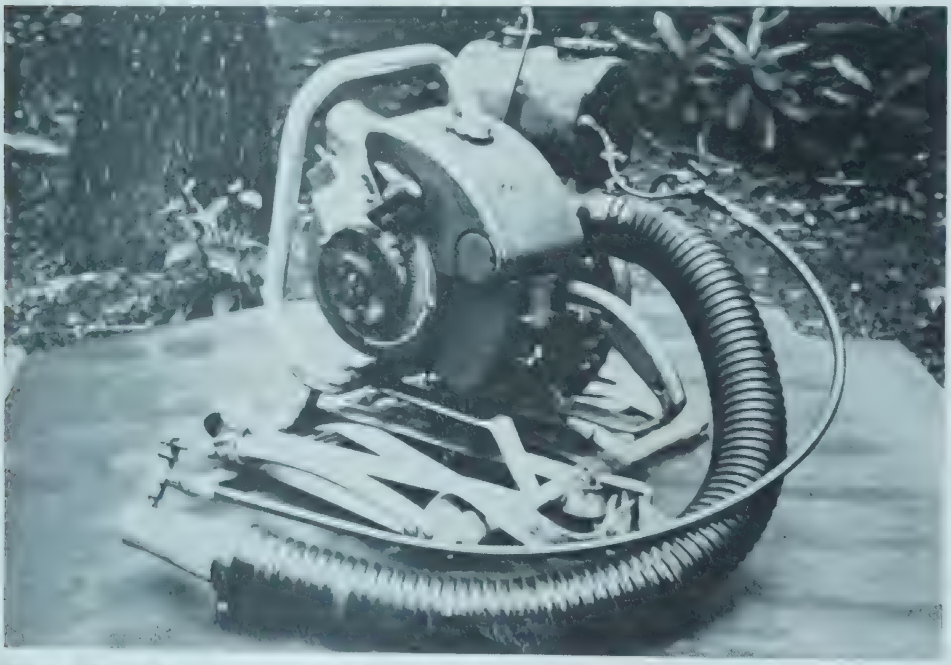


Figure 99. A two horsepower, 38 pound knapsack mist blower. In the picture the cushion for protecting the operator's back is lying flat against the ground.

Among the crop insects that may be controlled by the two methods just described are corn rootworms, field ants, Japanese beetle larvae, wireworms, cutworms, sod webworms, seed corn beetles, and seed maggots.

CRAWFISH (CRAYFISH) CONTROL. Experiments by the Mississippi Agricultural Experiment Station demonstrated that crayfish can be controlled effectively with either low gallonage ground sprayers or airplanes to apply a single application of two pounds of DDT in two gallons of emulsion concentrate per acre. The treatment should be made in the spring during March and April. It is effective on pasture and hay fields as well as on plowed land. Application should be made by aircraft if the land is too soft and muddy for ground machines to travel over.

Small Power and Hand Equipment

ELECTRIC HAND BLOWERS. A number of commercial electric, air-spraying units were investigated as to their efficiency for applying mist concentrates, but none of them were adequate. The chief faults of these units were: (1) a deficiency of air velocity to atomize the spray sufficiently, (2) insufficient air pressure on the liquid, or lack of air suction on the liquid to feed it properly, and (3) inability to apply suspensions.

The range in sizes for most purposes is between ⅓ and ⅔ h.p. High motor and fan tip speed is required to deliver essential, high velocities of 200 to 240 m.p.h. through outlets of ¾ to 1-inch in diameter. The simple, hollow tube liquid nozzles have given best results. The smallest power unit developed weighs 12 pounds (Figures 94 and 95), and consists of a multi-bladed centrifugal fan, a ⅓ to ½ h.p. high speed electric motor, and a removable outlet having a screw top to fit 1-, 2-, and 4-pint jars. The nozzle tip is a hollow tube, 3/32-inch in diameter, placed at the center of the outlet for applying any kind of concentrate. A needle valve on the feed line just above the jar top regulates the spray output. Within limits, the drop size can be increased with increase of liquid output.[*] The liquid is fed partly by suction and partly by air pressure from the fan. The air outlet is ¾-inch in diameter. Approximately 50 c.f.m. of air is delivered through it at about 200 m.p.h. This is sufficient air to atomize a maximum of five gallons of concentrate solution, emulsion, or suspension per hour. The liquid nozzle orifice from a hollow tube should be $\frac{3}{32}$ to $\frac{1}{8}$ inch in diameter. The motor and fan is a $\frac{1}{3}$ h.p. Electric Blower Co. Model[*] No. 2 that turns at 11,500 r.p.m.

---

[*] Potts, S. F., Philip Garman, Friend, R. B., and Spencer, R. A. Construction and Operation of Ground Equipment for Applying Concentrated Sprays. Conn. Agr. Sta. Cir. 178. 1950.

Some commercial units, such as Breuer's Tornado blower, Mist Master, etc., can be modified to deliver greater air velocity and volume by redesigning the outlet. Two redesigned $\frac{3}{8}$ h.p. units are shown in Figures 96 and 97. In this unit the outlet diameter is increased from $\frac{3}{4}$ to 1 inch to provide a 77 per cent increase in air volume. The nozzle formerly blocked off part of the air blast directly back of the orifice and the nozzle pointed with the air current which reduced the degree of atomization. Liquid is fed through a hollow $\frac{3}{32}$ or $\frac{1}{8}$ inch diameter tube to the center of the outlet where the air shears off the liquid at right angles. This nozzle also permits the use of suspensions. The spray output can be regulated by a simple valve that is attached to the liquid tube.

USES FOR ELECTRIC HAND BLOWERS. Electric hand blowers are limited by their dependence upon a source of electricity within 100 to 200 feet from the unit. Other limiting factors are their cost and limited capacity. Out-of-doors they can reach to a height of 12 to 20 feet, depending on their air capacity.

Their more important fields of use are for spraying shrubbery and turf around the home, restaurants, barns, camps, and greenhouses. When making applications with electric units, the information supplied on hand sprayers for treating walls, buildings, small trees, and yards is helpful. In treating green house plants, care must be exercised so as not to injure plants with over-doses, spotty coverage, and unsafe chemicals. One procedure is to calculate (see Tables) the minimum quantity of insecticide and the volume of finished mixture needed for a light to medium dose per 1000 square feet. If the foliage is dense, the quantity of spray can be increased somewhat.

Care should be taken to spray the space above the plants and make quick passes over the foliage with the outlet while standing in the aisles with the nozzle a few feet from the closest plants.

KNAPSACK MIST BLOWERS. A knapsack mist blower has been developed by the writer and R. A. Spencer in cooperation with the Homelite Corp. (Figure 99). It weighs 38 pounds and has essentially the same capacity as the wheelbarrow rig. Its main advantage is that with it a man on foot can get through some areas that are not accessible to wheelbarrow or skid model machines. Also, there is an attachment on it for operating a chain saw when the spraying unit is removed, and it seems to offer possibilities in fighting forest fires.

---

[*] Supplied by F. A. MacCallum of 352 Atlantic Ave., Boston, Mass.

The motor is a 2-h.p. air-cooled, two cycle type. The spray mixture is delivered to the nozzle by five pounds air pressure in the spray tank. The pressure is derived from the engine's cylinder. Rate of liquid output is regulated by a needle valve at the nozzle. The nozzle orifice is large (⅛-inch in diameter) to emit suspensions and is located in the center of the air orifice. There are two outlets, 1¼ and 1½ inches in diameter. With engine going at full speed the numerical average drop size was 26 microns for the 1¼ inch outlet and 46 microns for the 1½ inch outlet.

Small Skid and Wheelbarrow Models.* A small skid mist blower weighing 88 pounds (Figure 100) has been developed for applying solutions, emulsions and suspensions. This unit can be mounted on a horse, cart, trailer, tractor, truck or wheelbarrow. It can be regulated for applying ½ to 12 gallons of mixture per acre, using an operating pressure of 4 to 8 pounds p.s.i. The tops of 30-foot trees can be reached, and the spray can be drifted horizontally for 200 feet or more. It consists essentially of a small tank of 1 to 3 gallons capacity, a strainer in the spray pipe line, a gear pump, a pressure gauge, a valve, an atomizing nozzle and aluminum pressure blower, such as Allen Billmyre Model 10HR12, and a 1 to 2 h.p. gasoline engine, such as the 1.3 h.p. Lauson engine (Model R.S.C.). The blower on the units shown weighs 15 pounds. It delivers 160 c.f.m. at 225 m.p.h. through a 1¼ inch diameter air outlet attached to a 3-foot flexible 2¼ inch auto hose. The best operating speed for the blower fan is 8,000 to 10,000 r.p.m. Gear pumps (¼ inch size) (without built-in spring valve) are satisfactory when turning at 300 to 700 r.p.m. A maximum of two gallons of mixture per minute can be applied, but 5 to 12 gallons per hour is usually the best delivery for optimum drop size and coverage with the spray valve ⅓ to ½ open.

---

* Patent No. 2,454,339.

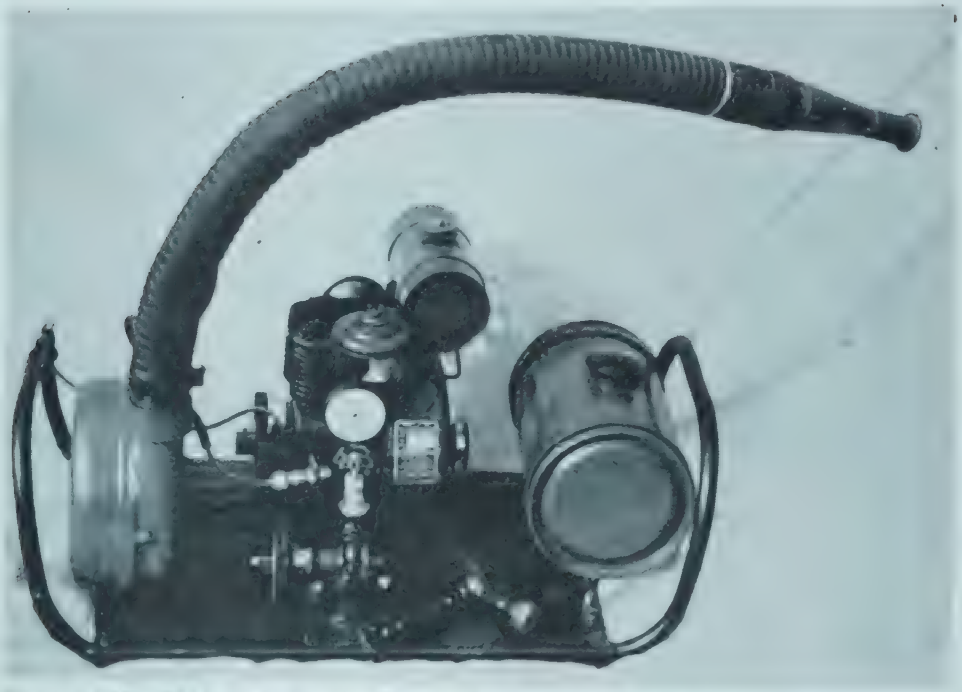


Figure 100 Skid model mist blower for mounting on a cart, small tractor, truck or wheelbarrow. Dry weight 88 lbs

Potts, Garman, Friend, and Spencer, 1950.

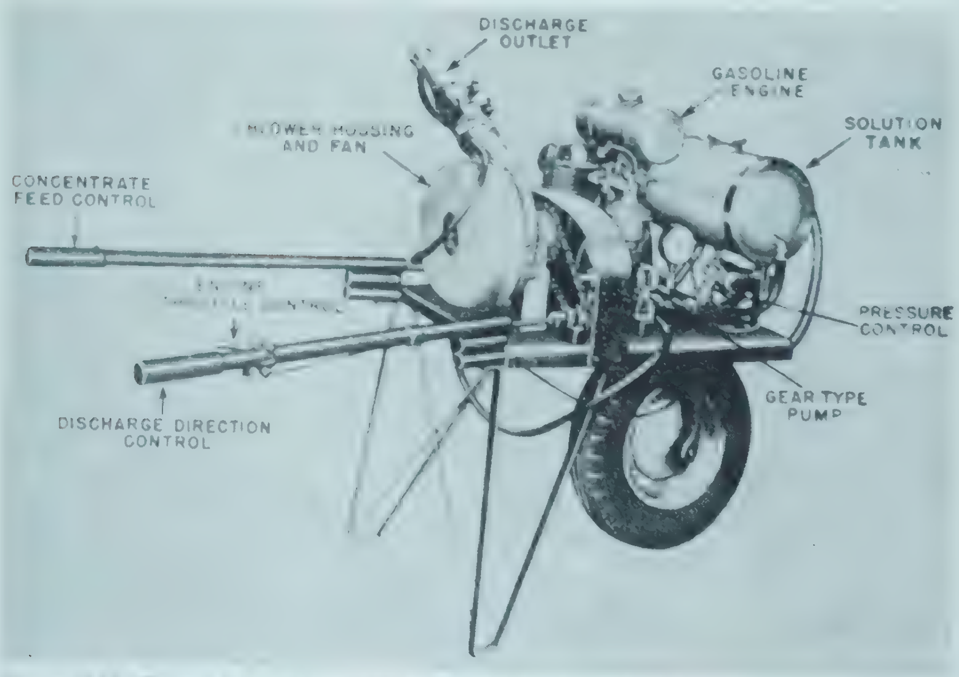

DISCHARGE OUTLET
GASOLINE ENGINE
BLOWER HOUSING AND FAN
SOLUTION TANK
CONCENTRATE FEED CONTROL
ENGINE THROTTLE CONTROL
PRESSURE CONTROL
GEAR TYPE PUMP
DISCHARGE DIRECTION CONTROL

Figure 101. Portable mist blower for small area control by Potts and Spencer

Potts, Garman, Friend, and Spencer, 1950.

Two kinds of nozzles have been used: (1) a direct-pressure type requiring 40 to 60 pounds pressure, and (2) a capillary-tube (air velocity) nozzle with four $\frac{1}{16}$- or one $\frac{3}{32}$-inch hollow brass tubes projecting from the periphery of a circular feed pipe for a distance of $\frac{1}{4}$ inch into the mouth of the outlet. The single $\frac{3}{32}$ inch tube in the center of the outlet is preferred for applying suspensions to reduce clogging. (Figure 103). The brass tubes are sharpened at their free ends to increase the shearing action of the air blast that passes over them at right angles. This unit and the wheelbarrow model have been described in detail by Potts and Spencer (1947).

The wheelbarrow model (Figure 101) weighs 140 pounds and was described earlier in its first stages of development.* Later, the machine was converted into a one man-operated outfit by making three important installations at the handles. The spray shut-off valve is opened or closed by turning the left handle grip sleeve. The engine throttle is also located at this handle. The grip sleeve of the right handle is similarly turned to rotate the blower cases and nozzle outlet. This permits the direction of the spray to any angle up or down from the machine while it is being pushed by the operator (Figures 101 and 102). A convenient means of tightening belts is arranged. A kick stand is provided to prevent the machine from overturning when standing on a steep slope.

The skid and wheelbarrow models just described are covered by a public service patent that permits manufacture by individuals in the continental United States without permission and without the payment of royalties.

SOME POINTERS ON OPERATING THE SMALL MIST BLOWER. When starting the machine for the first time, fill the crankcase with the required oil. Put gasoline in the tank and turn it on at the glass filter bowl. Then with hand throttle closed you are ready to start the engine. (A hand book for the engine and an operations folder should accompany each unit.) Close the valve that allows the spray material to go to the nozzle.

Next, while the engine is idling, pour the spray material into the tank through a wide-mouth funnel containing a 20-mesh strainer. This gives the engine time to warm up and prevents settling out of spray materials in tank and spray line. Keep the mixtures, tank, and screens clean.

---

* Potts, S. F. and Spencer, R. A., 1947. A small portable mist blower for applying concentrated Sprays. ET-234. USDA, BEPQ, processed.

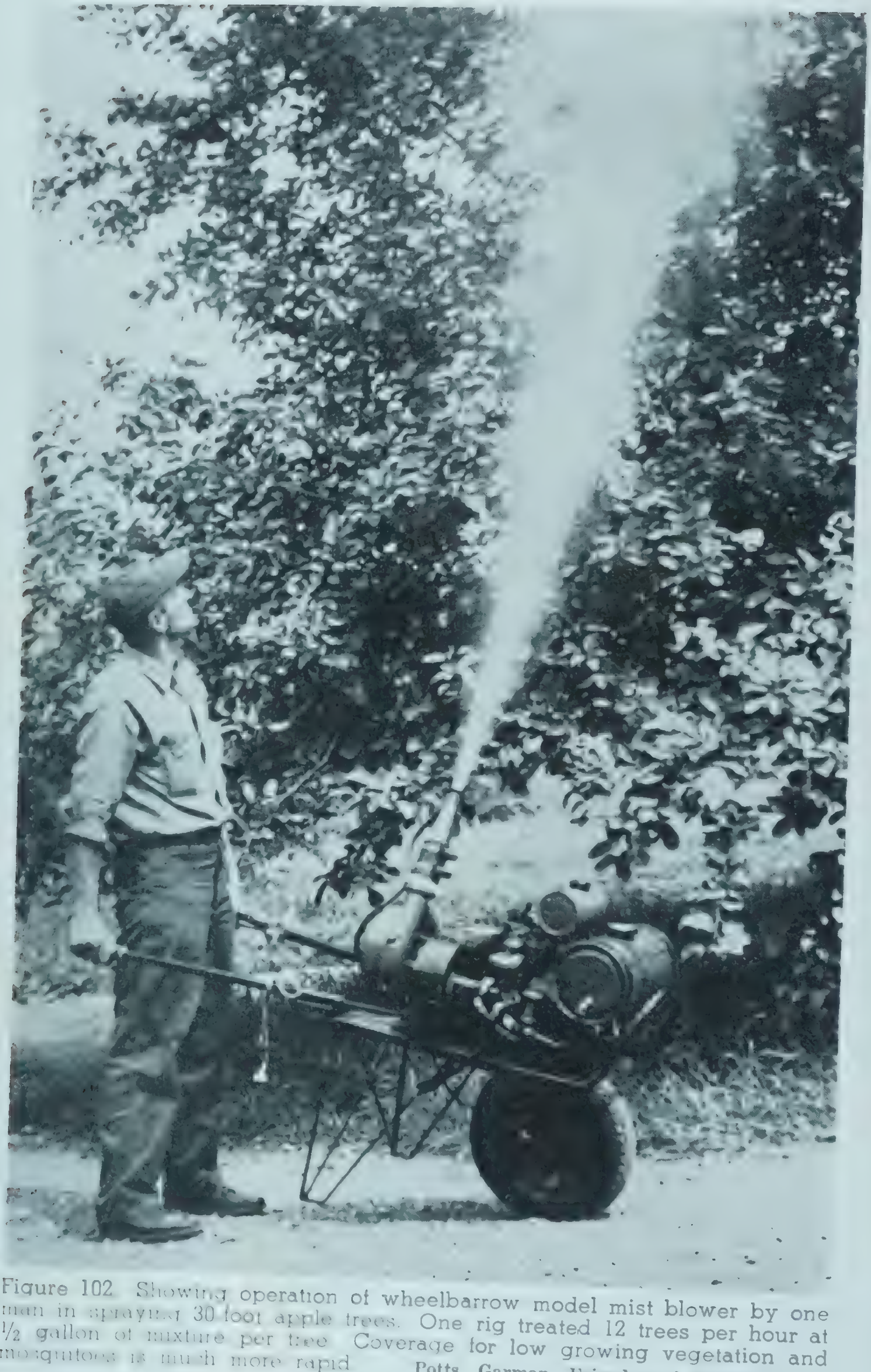


Figure 102. Showing operation of wheelbarrow model mist blower by one man in spraying 30 foot apple trees. One rig treated 12 trees per hour at ½ gallon of mixture per tree. Coverage for low growing vegetation and mosquitoes is much more rapid. Potts, Garman, Friend, and Spencer, 1950.

When spraying, the engine throttle should be wide open and the pressure regulated for five pounds by screwing down on the pressure gauge near the pump. (Too much pressure increases drop size.) Then open the valve on the hose line the desired amount, usually ½ to ¾ open.

Do not allow spray materials to stand and settle out in the tank. Most suspensions settle out rapidly. When through spraying flush out the complete system thoroughly with water.

Keep belts tight, check set screws in the pulleys, apply a little grease to the pump shaft occasionally, and keep the blower-rotating-bearing and chain oiled frequently.

Caution: Remember that this is a concentrate sprayer to apply, in most cases, only ½ to 12 gallons per acre. Do not expect to *wet down* the foliage, as this may cause foliage injury and waste material, too. Do not blast foliage close to the machine. Compute the area to be covered and the volume of mixture to be applied and watch the level of material in the spray tank. If you think you are not applying enough material, check it by holding a piece of clean glass or black paper in the spray stream 25 to 30 feet from the machine for two seconds. If your machine is set right you should find a medium light to medium deposit pattern of finely divided drops.

USES FOR THE SMALL SKID AND WHEELBARROW MIST BLOWERS. Uses for the above machines include the treatment of trees up to 35 feet in height; shrubs; low nursery stock that can be driven through without mechanical damage; broadcast treatment of lawns; one acre or less of large fruit trees, and larger areas of smaller trees; small areas of vegetables; small cranberry bogs; broadcast treatment of small to medium sized fields of pasture, clover, and peanuts; marshes and bogs; junk piles; livestock, barns, pens, and chicken houses; summer camps; recreational grounds; for use around schools, churches, and cemeteries; for student courses of instruction; and for use by spraying servicemen as auxiliary equipment in places where large rigs cannot reach.

The time required to treat an area depends primarily on the height of the trees or surfaces to be sprayed, the degree of coverage and penetration desired, and the volume of mixture to be applied. The treatment of tall fruit trees for combined control of all insects and diseases requires the greatest volume of spray (¾ to 1 gallon

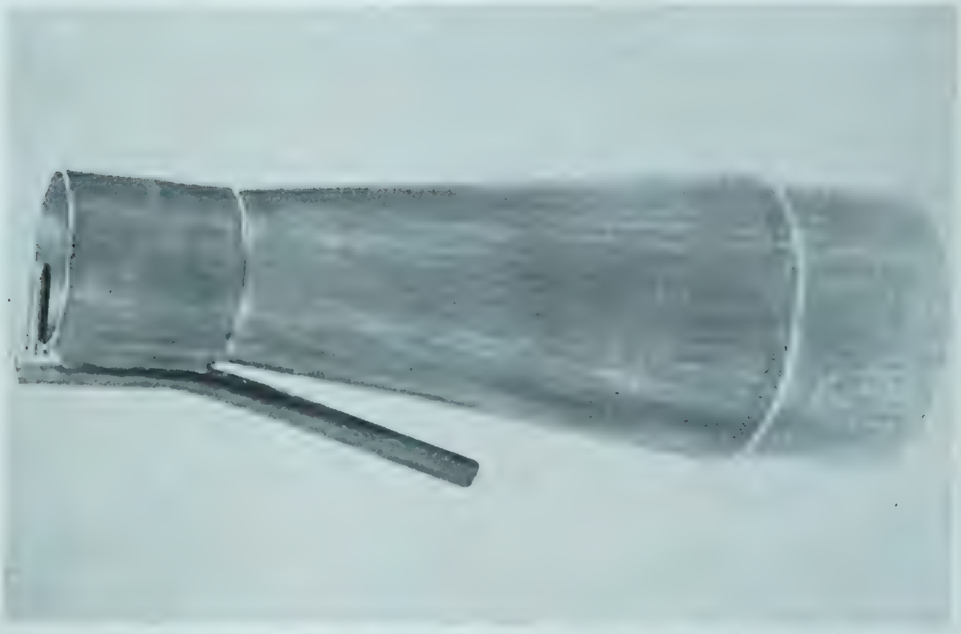


Figure 103 Single 3/32 inch hollow tube liquid orifice, located in center of 1¼ inch air orifice.

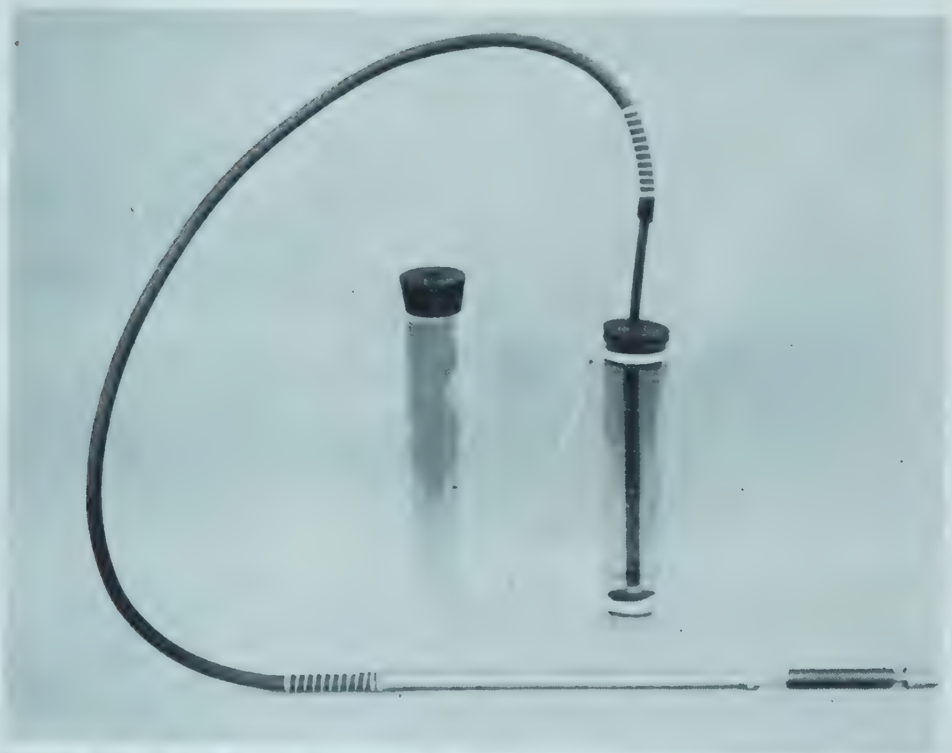


Figure 104 Six and eight ounce graduated cylinders with hose, adjustable nozzle, and hand pump.

for a big tree) and the slowest coverage rate. The fastest kind of coverage is illustrated in broadcast spraying for certain insects as mosquitoes on flat plains where swaths of 25 to 150 feet can be laid down with the help of the wind.

HAND EQUIPMENT FOR APPLYING CONCENTRATES. Hand equipment consists primarily of hand atomizers and knapsack sprayers or modifications of these two types.[*] For years the most widely used insecticide applicator for applying dilute sprays has been the simple hand atomizer. However, this instrument is much better suited for the application of concentrated sprays. It is not expected that hand equipment will have an important field of use for treating large fields and trees. Nevertheless, the application of concentrates increases the speed and ease of application to such an extent that hand apparatus can be used to treat much larger areas than could formerly be covered. The hundreds of uses for hand equipment include household spraying, the treatment of small yards and plants or shrubs under seven feet in height, lawns, flower and vegetable gardens, camps, stores, livestock and dairy barns. Hand equipment, therefore, is a concern of 40 million home owners and other potential users.

The present hand apparatus has many faults as well as virtues, and it is important that we know something of the different types, and how to improve, select and use them. A better knowledge of their use in the application of concentrated sprays is much needed, for very limited information on the subject is now available to potential users. A well conceived, well financed research program for the development and improvement of hand equipment is greatly needed. An adequate research, engineering, and educational program could easily increase the usefulness of hand atomizers 10 fold, and also increase the value of knapsack sprayers by several fold.

Hand atomizer. Most hand atomizers utilize a plunger type air pump to develop 2 to 5 pounds of air pressure. The air pressure may be applied to the surface of the liquid in the spray container to force it through nozzles with $\frac{1}{32}$ to $\frac{1}{16}$ inch diameter orifices. This is the continuous pressure type. In the other type, known as the intermittent sprayer, the liquid is drawn from the spray tank through a hollow tube by means of suction caused by air from the pump rushing across the open end of the liquid tube (Figures 105 and 106) with each forward stroke of the plunger. This latter type

---

[*] Potts, S. F. Application of concentrated spray with hand equipment. E-824. USDA, ARA, B.E. & P.Q., Memb. Oct. 1951.

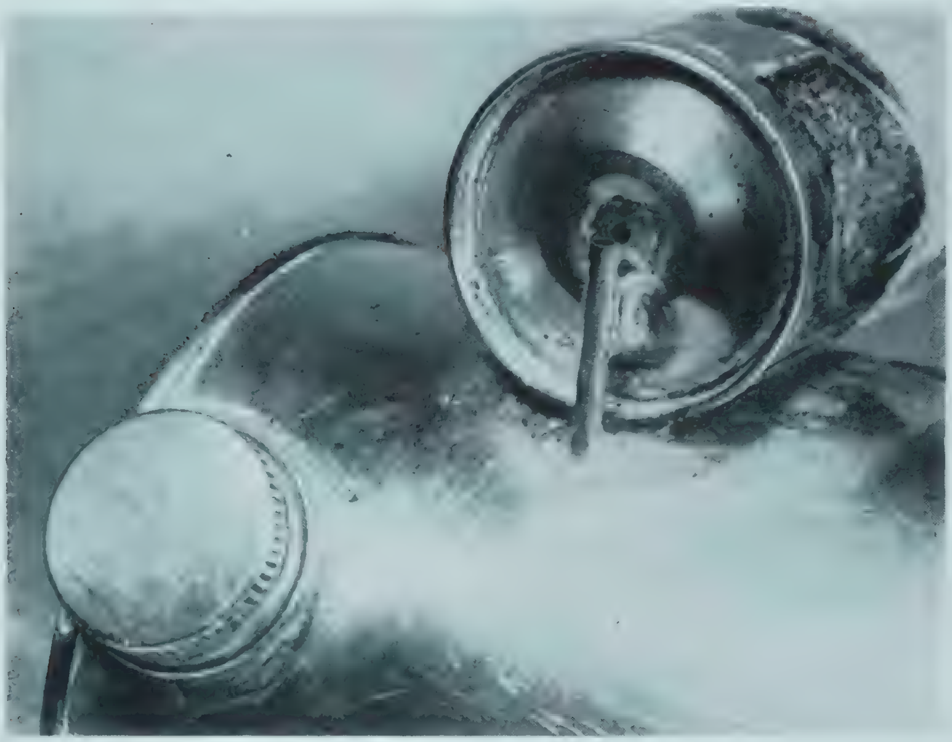


Figure 105. Intermittent hand atomizer showing proper relationship of air orifice to liquid orifice

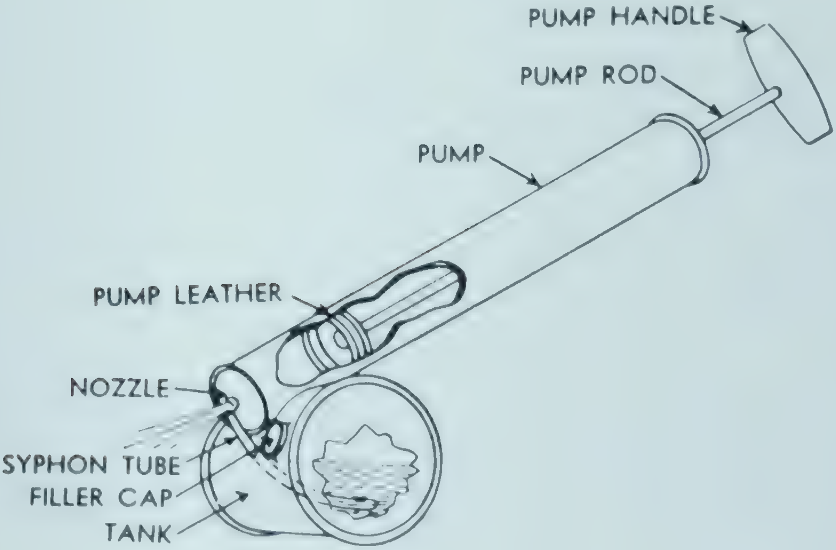

PUMP HANDLE
PUMP ROD
PUMP
PUMP LEATHER
NOZZLE
SYPHON TUBE
FILLER CAP
TANK

Figure 106. Structure of intermittent hand atomizer.

produces an average drop diameter of 15 to 50 microns and can handle spray suspensions as well as solution and emulsion sprays. It is usually preferred to the so-called continuous pressure atomizers referred to above which are more expensive and will clog when applying spray suspensions of wettable powders.

The suction feed type (Figure 105) ordinarily has an orifice of 0.1 to 0.15 inch (averaging 3/32 inch) in diameter. This orifice is large enough to avoid frequent clogging, and discharges liquid at a slow rate which permits fine atomization with less tendency toward overspraying. The air orifice is usually 3/32 to 1/8 inch in diameter.

The open end of the liquid tube should be from 1/32 to 1/16 inch forward of the air orifice and 1/16 inch below the center of the air orifice (Figure 105). The size and position of the liquid tube in relation to the position of the air orifice and the air pump is very important. When purchasing a hand atomizer such as the one shown in Figure 105, the consumer should keep this feature in mind. Less than half of the hand sprayers on the market have the air and liquid orifices in proper position in relation to each other. Single orifice atomizers have been superior to multiple orifice types. Selection of liquid and air orifices of the correct sizes has been discussed in Chapter II.

Many of the common faults or weaknesses of hand atomizers can be remedied by efficient construction. Some remedies would add to the cost of manufacture while others would not. The more important of these weaknesses are: (1) rusting and corroding of tank and liquid tubes, (2) short life of the air pump plunger, (3) tendency to drip the spray liquid onto floors or furniture while spraying, (4) inability of operator to see the liquid in the spray tank or to measure precisely the quantity of liquid that has been applied and the quantity that remains in the tank, (5) the difficulty of stirring the spray mixture in the tank, and (6) the difficulty of cleaning and rinsing the sprayer. The ordinary hand atomizer can be made more efficient by constructing a small diameter well in the bottom of the spray tank and having the suction tube extend to the bottom of the well to make it possible to discharge all of the liquid.

When the plants are two feet high or less, the operator is likely to tire unless an extension rod of 12 to 30 inches in length is used. Construction of extension rods or nozzles to permit directing the spray at any desired angle is helpful.

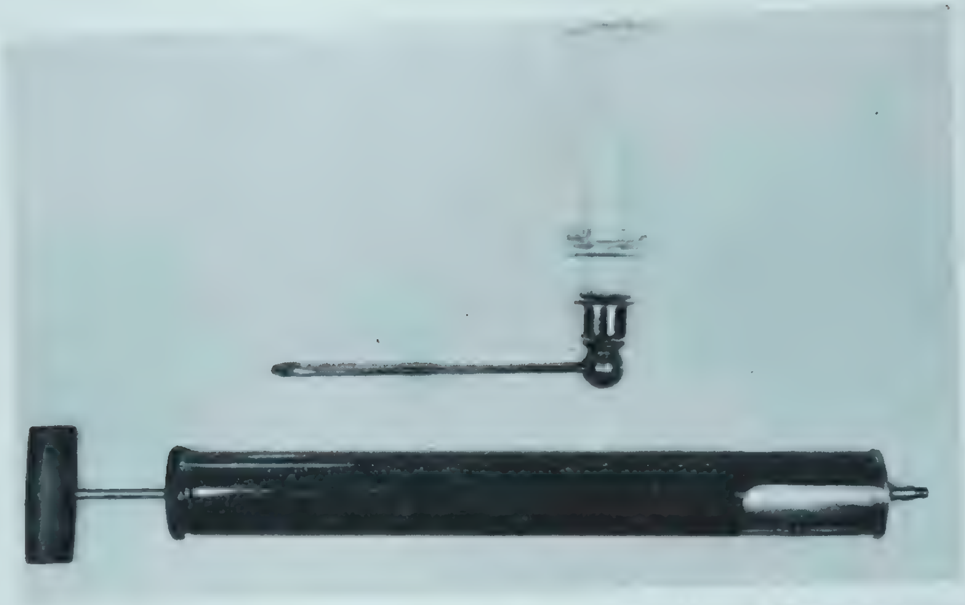


Figure 107. Above: Graduated, one ounce hand atomizer with hand pump detached

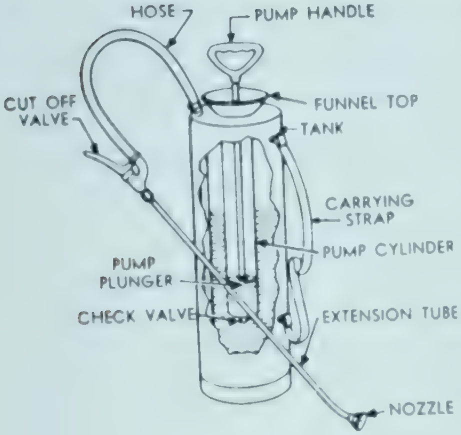
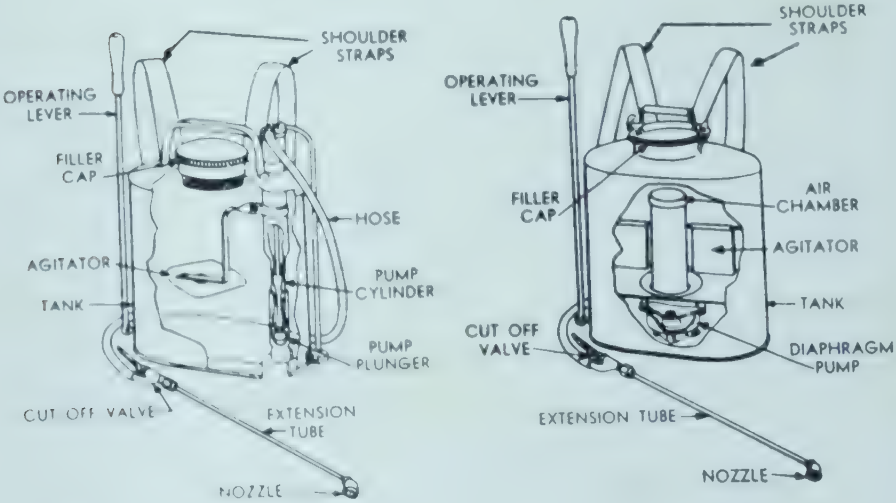

HOSE
PUMP HANDLE
CUT OFF VALVE
FUNNEL TOP
TANK
CARRYING STRAP
PUMP CYLINDER
PUMP PLUNGER
CHECK VALVE
EXTENSION TUBE
NOZZLE

Figure 108. At left: Showing structure of compressed air sprayer.

Figure 109. Below: Showing structure of knapsack sprayer


SHOULDER STRAPS
OPERATING LEVER
FILLER CAP
HOSE
AGITATOR
PUMP CYLINDER
TANK
PUMP PLUNGER
CUT OFF VALVE
EXTENSION TUBE
NOZZLE
SHOULDER STRAPS
OPERATING LEVER
FILLER CAP
AIR CHAMBER
AGITATOR
TANK
CUT OFF VALVE
DIAPHRAGM PUMP
EXTENSION TUBE
NOZZLE

Some difficulties of metal tanks can be avoided by using glass or plastics instead of metal. If tanks are of metal construction, sheets of prime galvanized or copper metal may be used. Protective paints or plastics are now available for coating tanks to prevent rust. Keeping the liquid feed tubes clean and open has always been a problem. Some practical way of installing a removable feed tube that could be readily removed and cleaned with a wire or pipe cleaner would be advantageous.

If the pump should lose its compression, withdraw the pump handle as far as possible and add a few drops of oil in the air hole at the end of the pump cylinder to lubricate the plunger cup or leather. After using, wash out the sprayer, drain it, and store in a dry place.

Precision type hand atomizers were designed by the author (Figure 107) for accurate delivery of specified small quantities of liquid. They consist of a hand air pump, such as is used on ordinary hand atomizers, with cap for screwing onto a transparent graduated glass cylinder that contains the liquid. The nozzle usually used was No. 152 de Vilbiss Nasal Atomizer type. Several sizes were made up ranging from 10 milliliters (⅓ ounces) to eight ounces in capacity. The 10 milliliter cylinder was graduated into 0.2 ml. markings while the larger sizes were marked in ml. and ounce divisions.

Hand atomizers can be used to apply as little as two gallons per acre, but for most uses the application should range from 4 to 6 gallons per acre for insects, hormones, and nutrients, and from 6 to 10 gallons per acre for diseases and medium to dense nursery stock or shrubbery.

COMPRESSED AIR AND KNAPSACK SPRAYERS are so named because air is compressed in the tank above the liquid (Figures 108 and 111). The essential parts are a tank (usually cylindrical) for spray material fitted with carrying handle or shoulder strap, pressure-tight filler cap, air pump for compressing air in tank, discharge tube which conveys the liquid in the tank to the discharge system consisting of hose, extension spray tube, spray control valve, strainer and nozzle. Compressed air sprayers are cheaper, easier to clean, and more popular than the handle operated diaphragm or piston pump knapsack sprayers (Figures 109 and 110). Compressed air sprayers are normally operated with 25 to 50 pounds air pressure on the liquid (Figures 108 and 109).

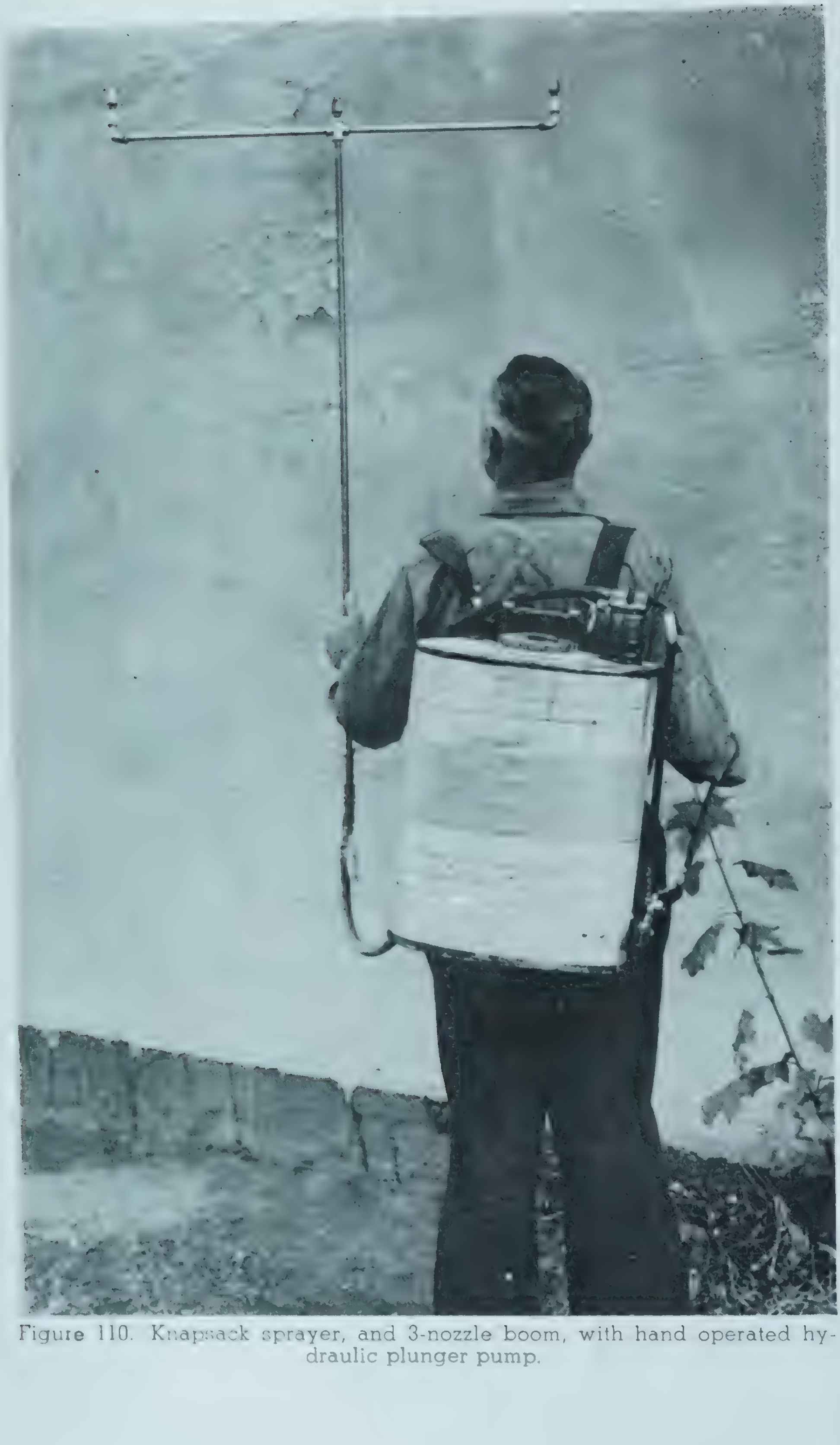


Figure 110. Knapsack sprayer, and 3-nozzle boom, with hand operated hydraulic plunger pump.

For special uses requiring a specified constant pressure, an auxiliary air tank is required with intake valve and a constant pressure regulator between the air tank and the liquid tank. Some models have CO_2 gas cylinders (Figure 112) to provide operating pressure. They discharge up to 15 gallons of material at uniform spraying pressure. Refilling cost is moderate. Use of the compressed gas permits utilizing the full capacity of the tank for spray material.

Knapsack sprayers. Knapsack sprayers (Figures 109 and 110 and 113), as the name implies, are carried on the back like a knapsack by means of two shoulder straps. The tank is shaped to fit the back, but is not always comfortable. Some makes have built-in liquid pumps of diaphragm or piston type which the operator pumps continuously while spraying. A pressure chamber reduces pulsations. Other models are provided with a double-acting external slide-type pump. Top pressures range from 80 lbs. for the internal type pump to 175 pounds for the slide type pump. Operation of the pump provides a mild form of mechanical agitation that is not sufficient however for wettable powder mixtures without occasional shaking. Pump handles may be attached at either side to permit right or left hand spraying.

Most knapsack sprayer tanks are made of galvanized steel, but some models are available in copper or stainless steel at additional cost. Tank capacities range from 4 to 6 gallons.

The ordinary back, fire pumps are not suited for applying concentrated sprays.

The common faults of present-day compressed air and knapsack sprayers are listed below together with some suggested remedies for manufacturers and users of such equipment:

(1) The hose is too short. A length of 4 to 5 feet is needed to provide reach and leverage.

(2) Sore backs are often caused by a poor back protection and leakage through the tops of knapsack sprayers. This is particularly serious when applying certain solvents and poisons. Proper back fits, padding, and tight covers would help.

(3) Gaskets and plunger rubbers and packings are readily decomposed by oil solvents as xylene, oils, and various other chemicals. Sprayers should be equipped with resistant materials.

(4) Some sprayers do not discharge all of the mixture in the tank.

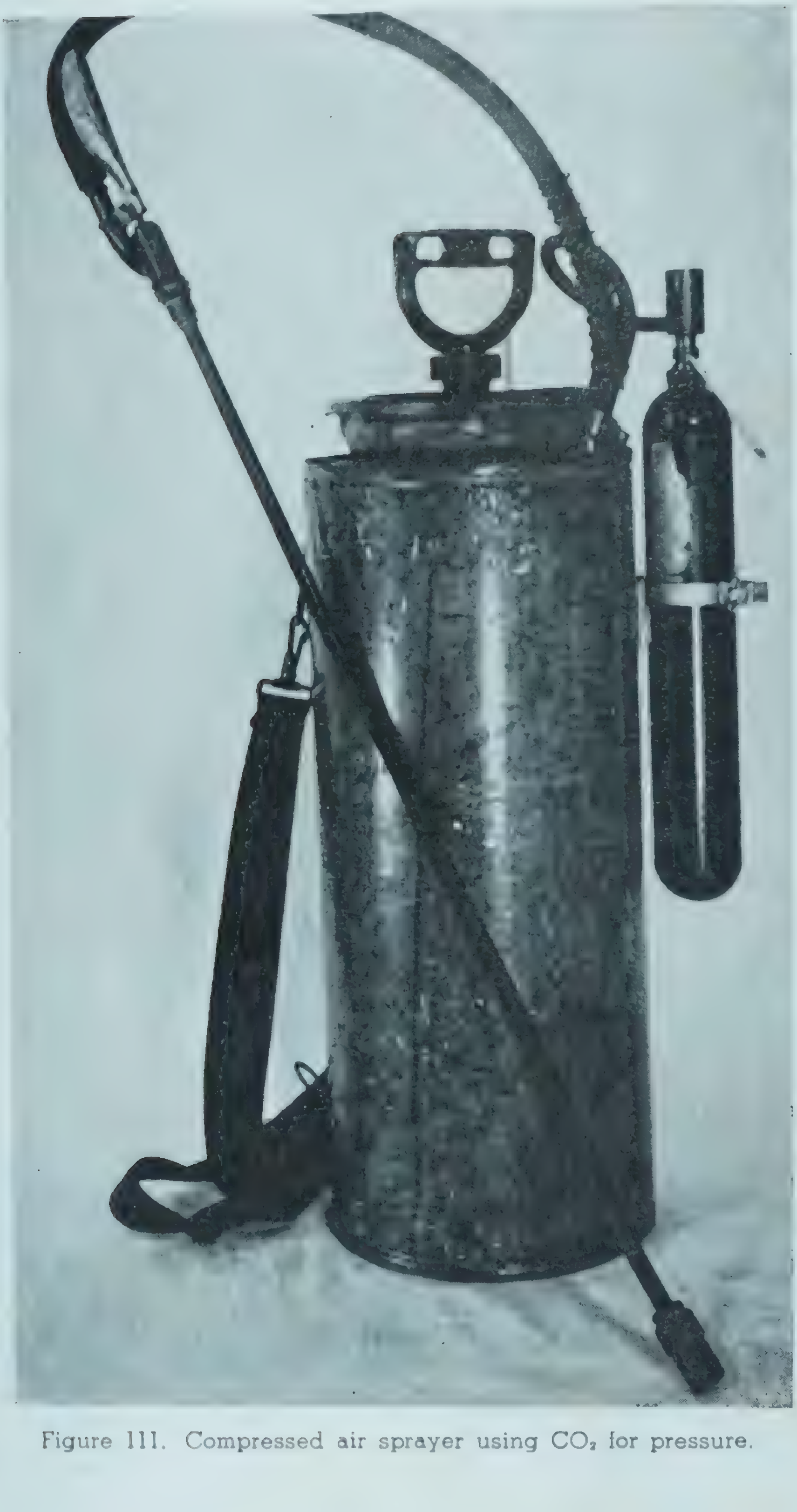


Figure 111. Compressed air sprayer using CO_2 for pressure.

(5) Most sprayers are not equipped with durable, dependable, leak-proof shut-off valves.
(6) Poor agitation.
(7) The tanks tend to corrode and rust. This can be prevented by coating the inside of the tank with a protective material and by prompt cleaning and drying.
(8) Extension rods longer than three feet are too heavy. A lightweight metal, such as magnesium, should be used. If it is still too heavy, the extension rod should be strapped on a bamboo pole or placed inside it by running the rod through a hole drilled the length of the pole.

ADAPTATIONS FOR LOW VOLUME APPLICATION. The unit should be capable of delivering accurately small amounts of spray mixture, discharge all the spray mixture in the tank, and be equipped with a nozzle that produces the drop size desired. In cylindrical types the discharge pipe intake should go within less than ⅛ inch of the bottom of the tank. Also, it can be inserted in a covered, small diameter well or cylinder. This permits discharge of all except one teaspoonful of liquid and prevents sloshing at the tank's bottom which allows air to get into the spray line, especially when the tank is not held in an upright position.

The 1 to 2 gallon compressed air tanks are better for most homes than the 3 to 5 gallon sizes.

In another apparatus not available commercially, a 500 milliliter cylinder was graduated into ounces and milliliters. It was of transparent glass to allow the operator to see at all times how much liquid remained in the cylinder. The spray liquid was forced out by a hand pump in the spray line. The apparatus weighs less than two pounds (Figure 114).

The use of compressed air and knapsack sprayers is limited by the rate of delivery and degree of efficiency of the atomizing nozzles.

Thus far, it has not been possible to use the ordinary knapsack sprayers extensively for applying suspensions of high concentration, because the large orifice needed to disperse wettable powders delivers too much liquid and the drops are too coarse.

Cone type nozzles, like whirljets No. 1 and No. 2, and some other relatively non-clog types that deliver 10 to 20 gallons per hour can be used. For example, if the operator travels two m.p.h. down 3 foot rows he will deliver 14 gallons per acre with the 10 gallon-per hour nozzle and 28 gallons per acre with the 20 gallon-per-hour nozzle. This permits using 4 to 8x concentrations of suspensions for insect and disease control. Fine, uniformly ground powders like lead arsenate can be used in 15x to 20x concentrations through 4 to 6 g.p.h. nozzles, but coarser materials like sulfur will clog them. A four g.p.h. nozzle (Spray Eng. Co. nozzle, No. I.S.) with 30-35 degree angle of spread is used to apply a 25x concentration of lead arsenate for controlling the white pine weevil. (Crosby, 1954)

However, cone type oil burner nozzles that deliver 2.5 to 6 gallons per hour are satisfactory for dispersing solutions and emulsion concentrates except where it is necessary to drive the mist to the undersides of dense foliage. By using these low gallonage nozzles it is not difficult to apply as little as 5 to 10 gallons per acre. Solution and emulsion sprays are usually applied at 20x concentration at the rate of 5 gallons per acre of low vegetation or 12.5 gallons per acre of good stockings of shrubbery (Table 53). The following gives an idea as to the rate of coverage with continuous spraying along one row of given width.

Row width in feet	M.p.h. travel	Acres covered per hour
1	1	.121
1	2	.241
1	3	.363
1½	2	.363
2	2	.483
2	1	.241
2½	2	.606
3	2	.726
3	1½	.544
4	2	.966
5	2	1.210
6	2	1.452

Nozzles from two or three companies have given good results with solutions and suspensions. The 100 to 200 mesh screens that came with them were removed and replaced with 40-mesh strainer for soluble chemicals and 20-mesh for powders. An adjustable angle, cone-type nozzle has been useful in cases where a change is desired in the spray angle and degree of atomization.

To avoid clogging, it is important to start with a clean tank and strain mixture into the spray tank through a funnel containing a 30 to 40 mesh strainer. The mixture should be shaken before and during the spraying operation. The application should be made with at least 35 pounds pressure. There should be a 14 to 20 mesh strainer on the intake pipe at the bottom of the tank. Rinse out the sprayer when the spray job is done, and hang it up to drain in a dry place with pump out and the top off.

HAND APPLICATION TO SPECIFIC CROPS. The requirements for general application have been discussed above. Some volume recommendations, or sources of recommendation, for specific crops are listed below.

Table 52. Dimensions of areas of given size for use in calculating the quantity of spray mixture to apply.

Fractions of an acre	Area in square feet	Dimensions of area in square feet
1.0	43,560	209*
1/2	21,780	147
1/3	14,520	120
1/4	10,890	104
1/5	8,712	93
1/8	5,445	74
1/10	4,356	66
1/12	3,630	60
1/15	2,900	54
1/20	2,178	47
1/25	1,742	42
1/30	1,452	38
1/40	1,089	33
1/50	871	29.6
1/75	653	25.5
1/100	436	21
1/200	218	15
1/400	109	10.5
1/800	55	7.4
1/1000	43	6.6

* 209 X 209 = 43,560 or 1 acre.

Cotton. Same as listed for low-gallonage machines and compressed air sprayers.

Corn. In treating other corn pests use 3 to 6 gallons per acre by hand atomizer, or 6 to 12 gallons by compressed air sprayers,* depending on the size of the plants and the insects concerned. For further information see Blanchard, Douglas, Wene, and Wooten, 1951.

Vegetables. For disease control by compressed air sprayers with suspensions, use 4 to 8x concentration, or 5 to 10 gallons per acre of 20x concentration in the case of solutions and emulsions. From 4 to 7 gallons per acre is suggested for hand atomizers, depending on stand density and volume of foliage.

For application of herbicides, fertilizers, nutrients. Hand atomizers: 4 to 6 gallons per acre. Compressed air sprayer: 5 to 10 gallons per acre for low growing vegetation and 10 to 15 gallons for well-stocked, fairly dense nurseries and shrubbery.

Mosquitoes and Flies. 2 to 4 gallons per acre.

Flower beds. Use hand atomizers, applying 12 to 20 ounces of mixture per 1,000 square feet (1.2 to 2 oz. per sq. ft.) of bed. Do not use oils, knapsack sprayers, overdoses, or unsafe materials.

HOW TO DETERMINE AMOUNT OF SPRAY TO USE. According to Dr. J. J. Davis, State Entomologist of Indiana, over 70 per cent of the insecticide purchased on the retail market is wasted. This can be avoided if the consumer will follow a few rules carefully, beginning with a scale of measurements as follows:

1 teaspoonful = 4.92 (or 5) milliliters (ml) = ⅙ ounce
1 tablespoonful = 3 teaspoonfuls = 14.78 ml
1 ounce = 29.57 ml, or 2 tablespoonfuls
1 pint = 16 ounces = 473 ml, or 2 cups
1 quart = 946 ml
1 gallon = 3,785 ml
1 ml is 1 cubic centimeter or 1/1000 liter
1000 square feet = .012 acre; 100 square feet = .0023 acre

The volumes of wettable powders in spoons, ounces, cups, etc., required for given dosages are given in the section on chemicals and formulations.

For treating shrubs, beds, gardens, or other areas of low growth it is necessary to know the size of the area to be treated (Table 52) and the gallons-per-acre rate to be applied, so that the volumes of mixture per unit area can be read from the tables below, which list

---

* Statements on compressed air sprayers apply equally to knapsack sprayers.

Table 53. Quantity of spray to apply for given volumes per-acre-rate, and for areas of given size.

Area in fractions of an acre	Volumes of spray required at the following gallons-per-acre rates.							
	1 gal	2 gal	4 gals	5 gals	7.5 gals	10 gals	12.5 gals	15 gals
1.0	1 gal.	2 gals.	4 gals.	5 gals.	7.5 gals.	10 gals.	12.5 gals.	15 gals.
1/2	0.5	1 gal.	2 gals.	2.5 "	3.75 "	5 "	6.25 "	7.5 "
1/3	2⅔ pts.	2⅔ qts.	1.33 qts.	6.66 qts.	2.5 "	3.33 "	4.15 "	5 "
1/4	1 qt.	2 "	1 gal.	5 "	7.5 qts.	2.5 "	3.17 "	3.75 "
1/5	1.6 pts.	3.2 pts.	3.2 qts.	1 gal.	1.5 gals.	2 "	2.5 "	3 "
1/8	1 pt.	1 qt.	2 "	5 pts.	7.5 pts.	5 qts.	6.25 qts.	7.5 qts.
1/10	12.8 ozs.	25.6 ozs.	3.2 pts.	2 qts.	3 qts.	1 gal.	5 "	1.5 gals.
1/12	10.65 "	12.8 "	2.66 "	3.33 pts.	5 pts.	3.33 qts.	4.16 "	5 qts.
1/15	8.5 "	17 "	1 qt.+1 oz	2.66 "	2 qts.	5.33 pts.	3.33 "	1 gal.
1/20	6.4 "	12.8 "	1.6 pts.	1 qt.	3 pts.	2 qts.	5 pts.	3 qts.
1/25	5.1 "	10.2 "	20.5 ozs.	1.6 pts.	2.4 "	3.2 pts.	4 "	2.4 "
1/30	4.27 "	8.53 "	17 "	1.33 "	1 qt.	2.66 "	3.33 "	2 "
1/40	3.2 "	6.4 "	12.8 "	1. "	1.5 pts.	1 qt.	2.5 "	3 pts.
1/50	2.5 "	5.1 "	10.2 "	12.8 ozs.	1.2 "	1.6 pts.	2 "	2.4 "
1/75	1.7 "	3.4 "	6.8 "	8.5 "	12.8 ozs.	17 ozs.	1.33 "	25.6 ozs.
1/100	1.28 "	2.56 "	5.12 "	6.4 "	9.6 "	12.8 "	1 "	19.2 "
1/200	0.64 "	1.28 "	2.56 "	3.2 "	4.8 "	6.4 "	8 ozs.	9.6 "
1/400	.32 "	.64 "	1.28 "	1.6 "	2.4 "	3.2 "	4 "	4.8 "
1/800	.16 "	.32 "	.64 "	.8 "	1.2 "	1.6 "	2 "	2.4 "

Table 54. Length of rows* or strips of given width required to equal fractions of an acre, from 1 1000 acre to one acre.

Width of row or strip in:		Distance of row or strip in feet to equal:								
feet	inches	1 acre	1/3 acre	1/5 acre	1/10 acre	1/50 acre	1/100 acre	1/400 acre	1/500 acre	1/1000 acre
1	12	43,560	14,520	8,712	4,360	871	436	109	87	44
2	24	21,780	8,712	4,356	2,178	436	218	55	44	22
2½	30	17,424	5,808	3,485	1,742	349	174	44	35	17.4
3	36	14,520	4,840	2,904	1,452	290	145	36	29	14.5
3⅓	40	13,200	4,400	2,640	1,320	264	132	33	26	13.2
3½	42	12,450	4,150	2,490	1,245	249	125	31	25	12.5
5	60	8,712	2,904	1,742	871	174	87	22	17.4	8.7
6	72	7,260	2,420	1,452	726	145	73	18	14.5	7.3
10	120	4,356	1,452	871	436	87	44	11	8.7	4.4

* Total length of row is the length of one row times the number of rows.

Table 55. Quantity of mixture to use for **each gallon** per acre rate.

Width of row in:		Linear distance of rows (or strips) in feet									
		one foot		10 feet		50 feet		100 feet		200 feet	
feet	inches										
1	12	.088 m.l.		.88 m.l.		4.4 m.l.	.9 tsp.	8.8 m.l.	1.83 tsp.	17.6 m.l.	3.7 tsp.
1½	18	.132		1.32		6.6	1⅓	13.2	2.7	26.4	5/6 oz.
2	24	.176		1.76	⅓ tsp.	8.8	1.83	17.6	3.7	35.2	7.33 tsp.
2½	20	.22		2.2	2/5	11	2.3	22	1½ tbps.	44	1½ oz.
3	36	.266		2.66	3/5	13.3	2.7	26.6	5/6 ozs.	53.2	1.8
3½	40	.31		3.1	7/10	15.5	½ oz.	31	1	62	2
5	60	.44		4.4	9/10	22	1½ tbp.	44	1½	88	3
6	72	.53		5.3	1.1	26.5	5/6	53	1.8	106	3.5
10		.88		8.8	1.83	44	1½	88	3	176	6
20		1.76	⅓ tsp.	17.6	3.7	88	3	176	6	352	12
25		2.2	2/5	22	5	110	3⅔	220	7⅓	440	15
30		2.64	3/5	26.4	5.5	132	4½	264	9	528	18
40		3.52	¾	35.2	7.33	176	6	352	11.8	704	1.5 pts.
50		4.4	1	44	1½ ozs.	220	7⅓	440	15	880	1.9
75		5.28	1.1	52.8	1.7	264	9	528	18	1056	2¼
60		6.6	1⅓	66	2.1	330	11	660	1.4 pts.	1320	2.8

Table 56. Quantities of sprays of different concentrations to apply to obtain various dosages of toxicant per 1,000 square feet ceiling, floor, or wall surface.

Percent of toxicant in Spray	2 grams	4 grams	8 grams	10 grams	15 grams	25 grams	50 grams	100 grams
1	7 fl. oz.	14 fl. oz.	1.7 pt.	2.2 pt.	3.3 pt.	2.6 qt.	5.2 qt.	10.4 qt.
2	3.5	7	14 fl. oz.	17.5 fl. oz.	1.6	1.3	2.6	5.2
3	2.16	4.32	8.6	11	1.1	1.7 pt.	3.4 pt.	3.4
4	1.7	3.5	7	8.7	12.5 fl. oz.	1.3	2.6	2.6
5	1.3	2.6	5.3	7.	10	16.6 fl. oz.	1.1 qt.	2.2
6	1.1	2.2	4.3	5.5	8	14	28 fl. oz.	3.5 pt.
7.5	0.9	1.8	3.6	4.5	6.7	11.1	22.2	2.8
10	20 ml.	1.3	2.6	3.3	5	8.3	16.6	2.1
12.5	16	1	2	2.6	4	6.7	13.3	26.6 fl. oz.
25	8	16 ml.	1	1.3	2	3.3	6.6	13.3

areas of given size and the quantity of mixture to apply. The quantities of spray required for small areas equivalent to various rates per acre are given in Tables 53, 54, and 55.

For treating barns, poultry houses, camps, and other buildings with residual sprays, the quantity to apply per unit area of floor, ceiling, and wall varies with the insect, the insecticide, the toxicant concentration, and the deposit desired. Table 56 lists quantities of sprays at different concentrations equivalent to given dosages of toxicant per 1,000 square feet (0.023 acre) of surface.

From the tables it can be seen that 87 milliliters (or essentially three ounces of spray) is applied per 1,000 square feet for each gallon-per-acre rate. For 100 square feet this amounts to 8.7 milliliters or 1.8 teaspoonfuls. For 2, 3, 4, 5, 6, etc., gallons-per-acre-rates, multiply these figures by 2, 3, 4, 5, 6, etc.

To improve coverage and accuracy make one or more practice applications of plain water to a measured area, using given application rates.

Soil Pesticide Injection Equipment

THE following information has been abstracted from material supplied by the Shell Development Company.

Two problems in applying soil pesticides are metering and distribution. These problems have become acute with the advent of highly active chemicals which are effective at 5 gallons per acre or less. It has been necessary to develop new techniques and equipment for their application since the currently available high-volume applicators are not sufficiently adaptable and precise. There are four general methods for the application of soil pesticides for which specialized equipment is necessary:

(1) Injection of volatile fumigants into the soil, the method in common use for the control of nematodes.

(2) Application of dust, emulsions, or solutions of pesticides in the seed row at time of planting.

(3) Mixing of dry or liquid chemicals into the soil for control of insects.

(4) Application of emulsions or solutions as drenches or combined with irrigation water for control of insects, nematodes, weed seeds, and fungi.

The discussion below is concerned with methods *(1)* and *(2)* and involves primarily the application of materials at dosages of 1 quart to 5 gallons per acre. The following is a summary of the current equipment as it applies to these methods:

PRESSURE ORIFICE SYSTEM. This method is used extensively, and is well known and readily available for high volume application in *(1)*. It will be discussed briefly since these new chemicals may in some cases be diluted economically and applied at the higher rates. A pump may be mounted so as to be driven from a belt drive attachment or power takeoff shaft. The pressure orifice system is generally mounted on a tractor equipped with a tool bar. An orifice and fittings are usually connected on the top of each chisel tube or are assembled in a manifold supported over the tool bar and connected to the chisels by tubing. A shipping drum may be used as a supply vessel and mounted on a tool bar platform or special racks. Two strainers are advisable, a 30 to 50 mesh at the tank and a 60 to 100 mesh at the manifold. A pressure gauge to operate between 20 and 30 p.s.i. should be readily visible to the operator. Connecting neoprene hoses and piping should not be less than ½″. Rate charts are available from suppliers to determine orifice sizes for various conditions of speed, spacing, and pressure.

References are included to cover a few of the types and suppliers.

Suppliers of complete kits

Fabricated Metals Company, 2400 Merced Street, San Leandro, Calif.

Insect Control Sales Service, Candor, North Carolina

Carter Insecticide & Chemical Company, Wallace, North Carolina

Suppliers for parts

Spraying Systems Company, 3201 Randolph Street, Bellwood, Ill.
  Orifice-Tee Jet Flow Regulator, DRWS. 4908, 6735, 5902
  Line strainer—DRW. 5950, #A ¾A TWB

Oberdorfer Foundries, Inc., Syracuse, N. Y.
  Bronze gear pump, Series 50, ¾″ with relief valve

Hypro Engineering Company, 404 Washington Avenue, N., Minneapolis, Minn.
  Roller type pump, Model 750, PTO drive

Gravity system with metering element. Gravity kits are lower in initial cost than the pressure orifice kits. They are more easily adapted to operate with plow, disc, or chisel tools since there is no need for pump power or extensive piping. More attention to calibration and tractor speed is necessary with this equipment, however, since rates are sensitive to variations of head and liquid temperature. The latest type of metering equipment developed for low volume (5 gallons per acre and less) for method *(1)* includes both a constant gravity head metering element and a land wheel drive pump.

Both the Insect Control Sales & Service and the Carter Insecticide and Chemical Company supply gravity kits primarily for high volume work. However, in the type discussed here, a coiled length of small diameter tubing is used instead of the calibrated needle valve and orifice plate, as used in their kits. This tube principle permits the use of a metering element with a diameter of .065″ for some of the lowest flow rates. Thus this relatively large diameter reduces the inaccuracy and tendency to plug that is experienced with smaller than .020″ diameters normally used in low volume application. The metering effect is the result of resistance or friction of the liquid going through the long length of tubing. Flow rates of liquid through this type of metering tube are a function of liquid viscosity, tubing, diameter, tubing length, and liquid head. Various combinations of the diameter, length and liquid head can be used to obtain the desired metering tube flow rate. In the field, changes in liquid head and tractor speed are the simplest means of controlling application rate. As an example, twice the head will approximately double the flow, and an increase in tractor speed will reduce the dosage inversely.

Figure 112 shows rate of treatment in ml. per foot for the desired gallons per acre to be applied at any desired row spacing. For calibration purposes, the ml. per foot figure is multiplied by the feet per minute of tractor speed, giving the ml. per minute. This figure is then the required flow rate of the element under field conditions.

Figure 113 shows a gravity head mettering tube element with a brush applicator for use in method *(2)*. Note the use of a plastic tube. Although this is adequate, it does not have the accuracy of a copper tubing element. Temperature and chemical effect on the plastic have a tendency to alter the diameter to the extent that approximately

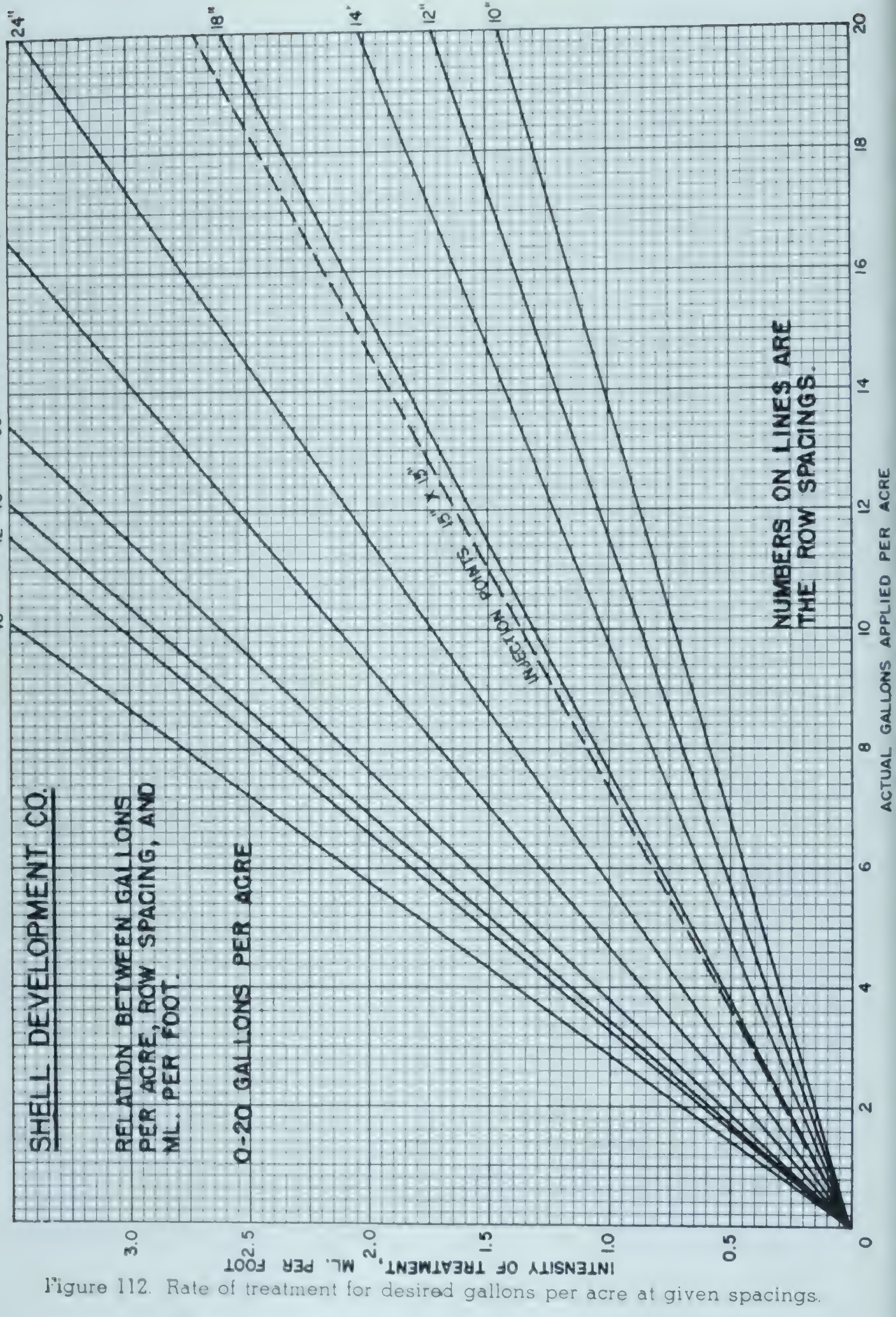


Figure 112. Rate of treatment for desired gallons per acre at given spacings.

10 per cent flow variations may result. Also in the extrusion process of forming the tubing, such variations in tubing diameter exist that it is often difficult to find two equal lengths from the same roll having the same flow rate. For this low gallonage seed row treatment, use of the brush applicator overcomes the deposit of the material in the form of discrete drops. The brush is constructed of approximately forty .012″ diameter spring steel wires 5″ long soldered around the end of a 12″ length of ¼″ or ⅝″ copper tubing. The brush is clamped to the rear of the seeder shoe or runner. It may be located so as to "paint" the material in the furrow at the seed level, to one side, or above it, if the brush is raised and set back slightly to a point of desired soil coverage.

LIVING PLANT TREATMENT. Under most conditions, the treatment of living plants does not involve any major changes in equipment or procedure, but the chemical must be *safe*. With well-established plants, such as grapes, tools which reduce the amount of root pulling are desirable. Use of a disc-type opener with a rolling cutting action would be acceptable if operable at the 6 to 8″ depth. It should be pointed out that with this disc type, a heavier drag-surface-seal operation is necessary. In seedling plants where a surface crust exists, a back sweep chisel as shown in sketch (Figure 114) would be preferable over the spear point type. With heavy soils, operation of a back sweep chisel creates a thrust-lift problem, if the tool bar cannot be stabilized.

CONSTRUCTION MATERIALS. In selecting construction materials, it is essential first to determine the degree of initial versus maintenance cost. The ferrous metals are suitable for short term use or where parts replacement is no great item, such as in the gravity metering element kit. Special attention to maintenance and cleaning will reduce replacement costs. Copper or brass are suitable for most application equipment and with a reasonable amount of cleaning will last through several seasons. The use of stainless steel is warranted in some cases where special chemicals are used or cleaning is a problem. There are plastics in the form of tanks, piping, etc. that will compete as a substitute for stainless steel in price and properties. For flexible lines Saran plastic is suitable. It may be desirable to use a flexible metal hose such as Rexweld in cases where pressure or mechanical drainage is a problem. Present studies indicate that the use of Neoprene is not advisable with Nemagon.

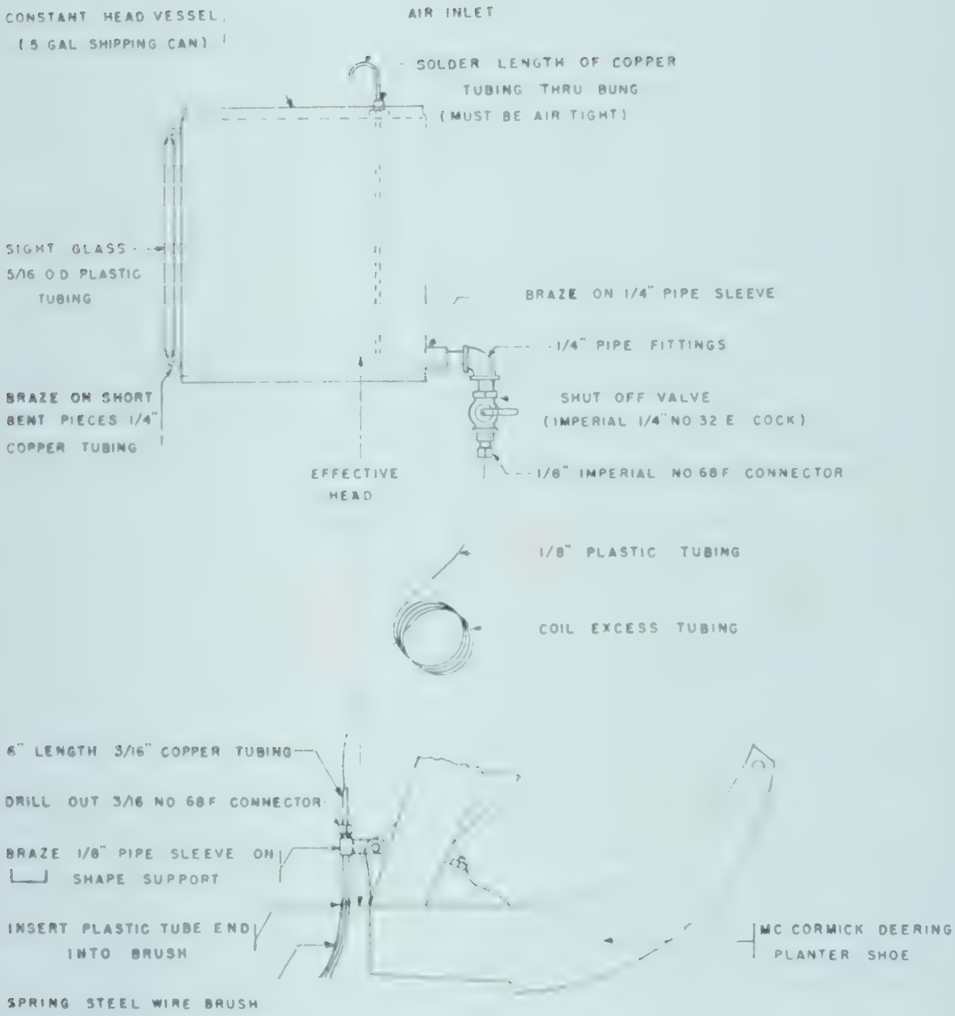

CONSTANT HEAD VESSEL
(5 GAL SHIPPING CAN)
AIR INLET
SOLDER LENGTH OF COPPER TUBING THRU BUNG (MUST BE AIR TIGHT)
SIGHT GLASS 5/16 O D PLASTIC TUBING
BRAZE ON 1/4" PIPE SLEEVE
1/4" PIPE FITTINGS
BRAZE ON SHORT BENT PIECES 1/4" COPPER TUBING
SHUT OFF VALVE (IMPERIAL 1/4" NO 32 E COCK)
EFFECTIVE HEAD
1/8" IMPERIAL NO 68F CONNECTOR
1/8" PLASTIC TUBING
COIL EXCESS TUBING
6" LENGTH 3/16" COPPER TUBING
DRILL OUT 3/16 NO 68F CONNECTOR
BRAZE 1/8" PIPE SLEEVE ON ⊔ SHAPE SUPPORT
INSERT PLASTIC TUBE END INTO BRUSH
SPRING STEEL WIRE BRUSH
MC CORMICK DEERING PLANTER SHOE

Figure 113. Equipment assembly showing metering tube and brush

Metering Element Specifications

For Tech. Nemagon at 75°F.
Based on 12″ row spacing
Speed—240′ per min.
Liquid head approx. 10″ to 12″

Gals. Per Acre	Copper Tubing Dimensions				ml. Per Min.
	O. D.	I. D.	Wall	Length	
1	⅛″	.065″	.030″	24″	21.
1	⅛″	.089″	.018″[a]	72″	21.
2.5	⅛″	.089″	.018″[a]	30″	52.
2.5	⅛″	.065″	.030″	6″	52.
5	3/16″	.127″	.030″	48″	105.
5	⅛″[b]	.095″	.15″	12″	105.
10	¼″[c]	.190″	.030″	72″	210.

Note
[a] Not standard wall thickness. Available as a special from the factory.
[b] Saran plastic tubing—not reliable to length.
[c] Also use for DD-20 gals. per acre.
Flows are generally not reliable for tubing length of 12″ and less.

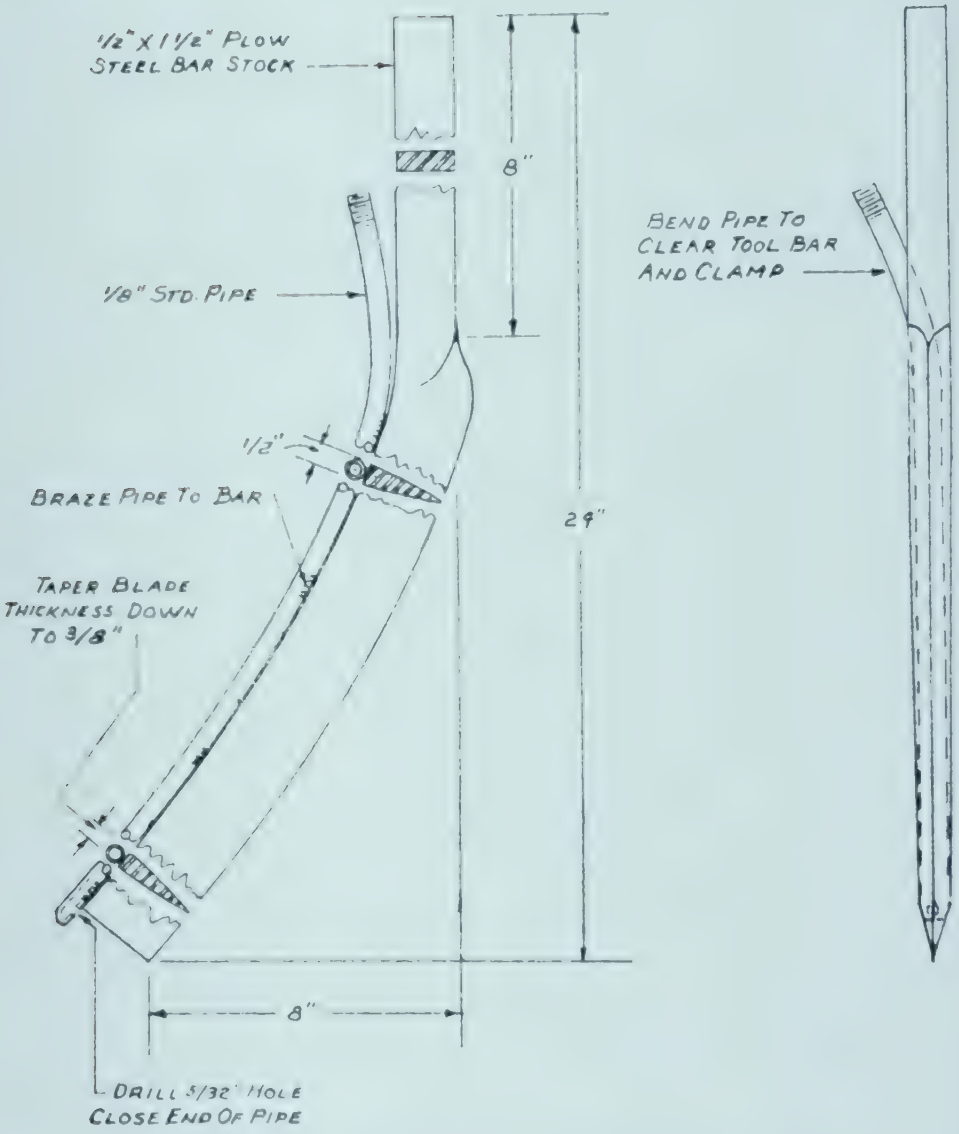

1/2" X 1 1/2" PLOW STEEL BAR STOCK
8"
1/8" STD. PIPE
BEND PIPE TO CLEAR TOOL BAR AND CLAMP
1/2"
BRAZE PIPE TO BAR
29"
TAPER BLADE THICKNESS DOWN TO 3/8"
8"
DRILL 5/32" HOLE CLOSE END OF PIPE

Figure 114. Back sweep injection knife construction detail.

Spray Equipment Manufacturers

Mist blowers for shade trees and general use:

- Machines of 7,000 to 30,000 c.f.m. capacity:
  - John Bean Manufacturing Company, Lansing 4, Mich.
  - Hardie Manufacturing Company, Hudson, Mich.
  - A. B. Farquhar Division, Oliver Co., York, Penna.
  - Buffalo Turbine Agr. Equip. Co., Gowanda, N. Y.
- Machines of 1,200 to 4,000 c.f.m. capacity:
  - Campbell Bros., 30 Deerfield Street, Greenfield, Mass.
  - Homelite Corporation, Port Chester, N. Y.
  - Hardie Manufacturing Company, Hudson, Mich.
  - Niagara Sprayer Co., Middleport, N. Y.
- Small skid and wheelbarrow models:
  - Cooley Spray Equipment Company, Somers, Conn.
- Knapsack units:
  - Kiekens-Dekker Co. (Distributed in the U. S. by Davies Tree Service, P. O. Box 1493, Palo Alto, Calif.)
  - Homelite Corporation, Port Chester, N. Y. (not in production as yet).
  - C. M. Voss, Box 91, RFD, Gettysburg, Pa.
- Orchard Sprayer:
  - John Bean Manufacturing Company, Lansing 4, Mich.
  - Hardie Manufacturing Company, Hudson, Mich.
  - Niagara Sprayer Company, Middleport, N. Y.
  - A. B. Farquhar Division, Oliver Company, York, Penna.
  - F. E. Myers and Bros., Ashland, Ohio
  - Friend Manufacturing Co., Gasport, N. Y.
  - Buffalo Turbine Co., Gowanda, N. Y.
  - Homelite Corporation, Port Chester, N. Y.
  - Robinson Fan Corporation, Gilroy, Calif.
  - Bessler Corporation, Oakland 8, Calif.
  - Cordox Corporation, Bell Building, Chicago 1, Ill.
  - Also, see The *American Fruit Grower's* list of spray equipment.
- High clearance, low gallonage machines:
  - Hahn Hi-Boy Mfg. Co., Gary, Ind.
  - Warren Manufacturing Company, Inc., Monmouth, Ill.
  - Also, see tasseling machines.
- Valves:
  - W. L. Hamilton and Company, Bangor, Mich.
  - Spraying Systems Company, 3278 Randolph Street, Bellwood, Ill.
  - Spray Engineering Company, 114 Central Street, Somerville, Mass.
  - Crane Company, 836 S. Michigan Ave., Chicago, Ill.
  - Jenkens Valves Company, Bridgeport, Conn.
  - Monarch Works Manufacturing Co., Philadelphia, Penna.
  - Also sprayer companies.
- Nozzles:
  - Spraying Systems Company, 3278 Randolph Street, Bellwood, Ill.
  - Monarch Manufacturing Works, 3406 Miller Street, Philadelphia, Penna.
  - Spray Engineering Co., 114 Central Street, Somerville, Mass.
  - Bete Fog Nozzle Inc., Greenfield, Mass.
  - Eddington Metal Supply Company, Eddington, Pa.
  - H. D. Hudson Manufacturing Company, 589 Illinois St., Chicago, Ill.
  - Root-Lamell Corporation, 445 N. Lake Shore Drive, Chicago, Ill.
  - Cooley Spray Equipment, Somers, Conn.
  - Also see: Orchard sprayer companies and *Entoma*.

Literature Cited

American Mosquito Control Association. 1952. Ground equipment and insecticides for mosquito control, Bul. No. 2, 150 pp., illus.

Black, D. T., L. P. Ditman, and G. J. Burkhardt. 1954. A high-clearance self-propelled sprayer for sweetcorn. U.S.D.A. Cir. No. 946, 13 pp., illus.

Blanchard, R. A., W. A. Douglas, G. P. Wene, and O. B. Wooten. (rev.) 1951. DDT sprays for control of the corn earworm and the budworm in sweetcorn. U.S.D.A. Bur. Ent. and Plant Quar., E-780, 12 pp.

Borden, A. D. 1952. Low volume spraying of deciduous fruit trees successful with air carrier speed sprayers. Calif. Agr. Expt. Sta. 2(6): 5, 16.

Brann, J. L. and W. W. Gunkel. 1953. New mist concentrate sprayer for crops. *Farm Research*. N. Y. Agr. Expt. Sta., Vol. 6, No. 2.

Brown, C. R. 1948. Progress report on the Cornell low-volume flexible outlet spray-duster. N. Y. State Hort. Soc. Proc. 93: 93-100.

Burrell, A. B. 1951. Efficiency in spraying with special consideration of concentrates. *Amer. Fruit Grower* 71(2): 61-76.

Crosby, D. 1954. How to control the white pine weevil with a hand sprayer. U. S. Forest Service Research Note No. 30, 34 pp.

Garman, P. 1953. A study of spray machines in Connecticut orchards. Conn. Agr. Expt. Sta. Bul. 567, 34 pp., illus. 1953.

Gunkel, W. W. 1954. Durability tests of some agricultural sprayer pumps. Cornell Agr. Expt. Sta. Bull. 915, 43 pp., illus.

Mitchell, A. E. 1949. Application of concentrate sprays with a speed sprayer. Agr. Eng. 30: 533-534.

Peikert, F. W. and R. Bonde. 1954. Potato disease and insect control with low gallonage sprayers. Maine Agr. Expt. Sta. Bul. 527, 16 pp., illus.

Potts, S. F. 1940. Equipment available for applying concentrated sprays. U.S.D.A. Bur. Ent. and Plant Quar. E-574, 7 pp., illus.

————. 1946. Particle size of insecticides and its relation to application, distribution and deposit. *Jour. Econ. Ent.* 39(6): 716-720.

————. 1951. Application of concentrated spray with hand equipment. U.S.D.A. Bur. Ent. and Plant Quar., E-824, 6 pp., illus.

———, and R. B. Friend. 1946. Mist blowers for applying concentrated spray. Conn. Agr. Expt. Sta. Bul. 501, pp. 47-60.

———, and R. A. Spencer. 1947. A small portable mist blower for concentrated spray. U.S.D.A. Bur. Ent. and Plant Quar., ET-234, 3 pp.

———, A. C. Cline, and H. L. McIntyre. 1942. The white pine weevil and its control by the application of concentrated spray. *Jour. Foresty* 40: 405-410.

Potts, S. F., R. A. Spencer, and R. B. Friend. 1953. Tests of a light-weight mist blower. Conn. Agr. Expt. Sta., Bul. 572, 12 pp.

———, P. Garman, R. B. Friend, and R. A. Spencer. 1950. Construction of ground equipment for applying concentrated sprays. Conn. Agr. Expt. Sta., Cir. 178, 35 pp.

Pratt, R. M. 1948. Status of the Cornell sprayer-duster. N. Y. State Hort. Soc. Proc. 93: 87-93.

Waters, H. W. 1953. Spray equipment. *Agr. Chem.* 8(6): 34-35, 163.

Wilson, J. D. 1952. *The Pesticide News* 5(2): 42-44.

Wooten, O. B., W. R. Smith, and W. E. Meek. 1950. Cultivator spray rig for farm tractor. Miss. Agr. Expt. Sta., Bul 472, 19 pp., illus.

Yeomans, A. H. and E. E. Rogers. 1950. Special report IN2-22. U.S.D.A. Bur. Ent. and Plant Quar., 22 pp., illus.

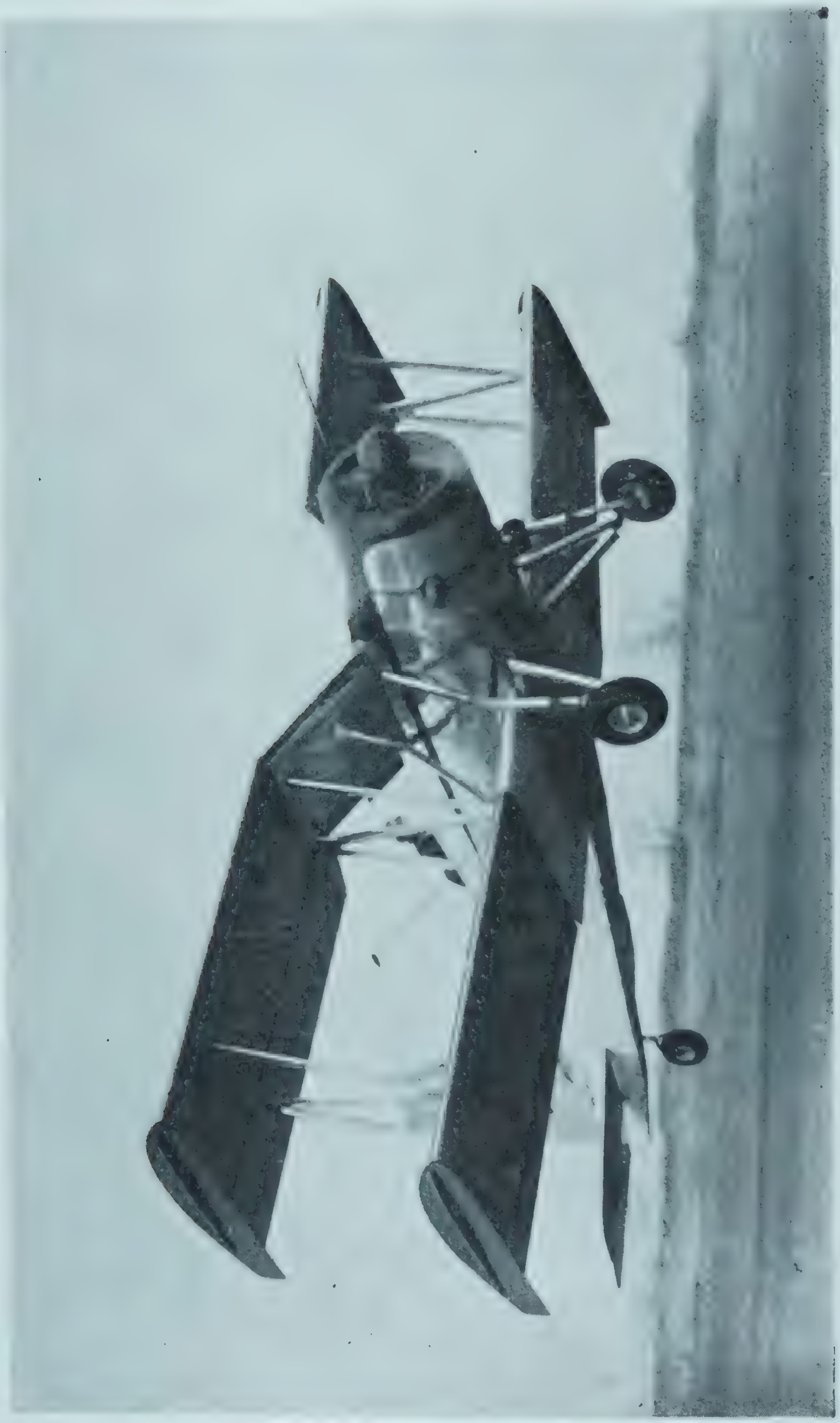


Figure 115 Larson Air Tractor

CHAPTER IV

AERIAL EQUIPMENT

CHAPTER IV is divided generally into two sections. Following a brief discussion on "History" the *first* section consists of non-technical information on how to spray for farmers, conservationists, and public health departments and for spray-plane pilots. The *second* section, beginning with "Installation of Spray Equipment" deals with installation details and the mechanical, experimental, technical, and long range phases of aircraft spraying.

Economic and Developmental Status

In 1935 only a few hundred acres were sprayed by aircraft. These areas were mostly woodlands, and autogiros did most of the flying. A rapid increase in aerial spraying began in 1944, and ten years later (1954) nearly 20 million acres were sprayed by aircraft, mostly with airplanes. Spraying has already moved ahead of dusting by a ratio of 1.4 to 1, and this ratio is steadily increasing in favor of spraying.

The first aerial spraying was for controlling insects. However, the field of spray concentrate dispersal has expanded to include the application of fungicides, herbicides, silvicides, hormones, defoliating chemicals, dehydrating compounds, fertilizers, nutrients, seed suspensions, insect viruses, and a host of other uses. The potential area for ground and aerial application of concentrates will very probably reach 100 million acres in the next 10 years. This increased use will be spearheaded by the development and production of improved aircraft suited for forest and agricultural usage, further improvement in spraying apparatus and techniques, new chemicals and formulations, and adequate instruction and dissemination of information to potential users. Such a program requires considerable work, study, and testing by workers in supporting sciences, particularly aeronautics, engineering, chemistry, botany, animal physiology, plant physiology, forestry, and agronomy. But in looking to the future we must not forget the present backlog of unfinished business and unsolved problems.

History

Since 1943 and the introduction of DDT for pest control, a number of widely scattered reports have been published on aerial spraying,—most of which are of an exploratory nature. However, prior to 1943 very little material was published. Between 1930 and 1942 the author published six reports on concentrated spray equipment and formulations for aircraft. Two of these papers (Potts 1929 and 1940) mentioned the work done between 1927 and 1935. But they do not include the great deal of information and designing that came out of that investigation.

Specifically, the idea for applying insecticides in concentrated spray form arose from the need for a cheap, rapid method to replace the slow, difficult, expensive task of applying large volumes of spray mixture per acre of woodland with high pressure, hydraulic sprayers.

Hence, a series of studies on airplane dusting (1926-1927), smoke aerosols (1927-28), dust adhesives, oil-coated dust and spray-dust or wet dust led to research started in 1928 by the author on concentrated sprays. From 1929 to 1934 during the depression era, the Massachusetts Institute of Technology, through Dr. Karl O. Lange, made one of their planes available for frequent tests. Some 300 pages and diagrams of proposed equipment and techniques were prepared. During these studies, a boom with liquid hydraulic nozzles was developed. It had to be abandoned until 1943, when solutions came into use, because most of the insecticides were in powdered form,—like lead arsenate, which required some pump pressure and tank agitation to prevent clogging. This resulted in the development and temporary use of centrifugal atomizing devices with gravity liquid flow, and often very high concentrations and high viscosities to prevent settling out of suspensions. The spinner apparatus was used on autogiros and on airplanes until about 1948. A significant study was published in 1946 by Potts on particle size, distribution, and deposit. It summarized some of the more important findings on this subject from 1928 to 1942, prior to the use of DDT as an insecticide. During that period, over 150 pages of outlines, suggestions, and 75 diagrams of apparatus were drawn. However, it was extremely difficult to obtain funds or professional and project acceptance for these studies.

From 1940 to 1953, the writer did practically no work on aircraft apparatus because of official assignment to other projects, but he was still able to conduct many experiments on formulations, particle size, and deposits that are applicable to airplane application. From

1943 to the present several well financed projects have been set up, and several staffs are engaged in the studies.

No attempt will be made here to cover the literature, but appropriate references are listed throughout the text, where they are of special value. A bibliography covering the period to 1945 has been compiled by Hawes and Eisenberg (1947), and many references up to 1948 have been reviewed by Brown (1951). Yuill, Eaton, and Isler, made a summary of aircraft spraying for forest insects in 1951. Special mention should be made of three other U. S. Department of Agriculture reports: Aircraft for Spraying and Dusting (1948), How to Spray the Aircraft Way (1954), and Studies of Airplane Spray-Deposit Patterns at Low Flight Levels (Chamberlin, Getzendaner, and Hessig, 1955). Two annual conference reports of considerable value are: Texas Agricultural Aviation Conference (1952 to 1955), and the Agricultural Aviation Research Conference (1954 and 1955).

How to Spray with Aircraft

FARMERS and foresters everywhere are finding that the application of modern pesticides gets results. Ground equipment is best for some jobs, aerial equipment for others. On the ground or in the air, one can dust or spray. The following material gives farmers a basis for appraising the value of aircraft spraying, and tells how to plan spraying jobs to suit individual needs. It gives spray-plane pilots information about such matters as equipment, aircraft performance, and safety. Information on pesticide chemicals and mixtures is given in Chapter V. Calibration of equipment and mixtures is given in Chapter II.

Labor, equipment, spray material, and your own time all cost money. Talk over your anticipated spray program with your county agent, state experiment station, the United States Department of Agriculture, and pesticide manufacturers and distributors. Ask yourself two questions: (1) Do I really need to spray? and (2) Is my crop going to be good enough to make spraying worth while?

"How to spray the Aircraft way" (1954), is a simple, useful guide for farmers and spray-plane pilots. Most of the material on the several pages that follow is either condensed or quoted from that publication.

The grower should get the job in focus by considering the types of sprays, whether to use ground or aerial equipment, and whether to spray or dust. There are three major types of sprays: solutions, emulsions, and suspensions. Sometimes a suspension, if allowed to stand or settle out, clogs the pump and causes it to "seize." Although emulsions have little tendency to clog equipment, they may separate if allowed to stand too long. Both emulsions and suspensions require agitation during spraying operations. Learn all you can about the various liquids you handle. At one time or another you may work with various insecticides, fungicides, herbicides, defoliants, and fertilizers.

The trend is more and more toward spraying rather than dusting. Ordinarily, sprays give a wider and more uniform swath, too, since they can be piped and discharged along the span of a plane's wings. And since spray particles are usually heavier than dust particles, they are less likely to drift. That means the plane can fly higher and cover a wider swath. When sprays reach the crop they stick better than dusts; rain and wind are not so likely to wash them off plants, and the deposit is heavier.

Whether you spray with aerial equipment or with ground equipment depends on the size of your farm, the lay of your land, the crop to be sprayed, and the insect that you are fighting.

"Some insects are in places that are hard to reach with ground equipment. Examples are grasshoppers, when they occur on rough rangeland, and forest pests. In such places you can do a more efficient job with aerial equipment.

"Insects on certain truck and field crops are easier to control with ground equipment. One reason is that the pesticide may get further down into the crop when applied from the ground. Another reason: Some insects don't move about; the spray has to land directly on them in order to kill them, and they may escape direct hits from spray applied by plane.

"Here are some strong points of aerial spraying:

1. Big outbreaks of insects can be treated with great speed.
2. Insects, diseases, and weeds can be treated without disturbing growing crops.
3. Properly equipped and operated airplanes put out sprays efficiently, and can be used in a wide variety of situations.
4. Planes can keep right on spraying when fields are too wet for ground equipment.

"These advantages have strong appeal, but let's sum up from the other side of the fence:

1. It's harder to control spray distribution from planes. Wind or other factors may carry insecticides beyond the field that

you want to treat. If the wind is too strong, you may not be able to spray at all.

2. You can often treat small acreages more cheaply with ground equipment.
3. Since most farmers don't own planes, they have to hire commercial operators to spray for them—and that means a cash outlay when cash may be scarce.

"If you shy away from aircraft spraying because your acreage is too small to justify the spraying cost, look into the possibility of forming a spraying ring. It may be that you and some of your neighbors can arrange to have several small fields sprayed in one operation."

Spraying Personnel consist of . . . "ground crews to load the planes and keep them in condition, and supply men to see that pesticides and auxiliary equipment are on hand when needed. There must be someone to organize and supervise the job. The pilot or his supervisor usually has the responsibility. He has the spraying done at the right time of day and at the right altitude, and keeps an eye on the weather.

"Start your planning as soon as you have decided to do business with an aerial-spraying operator. Planning falls into four main divisions: Preparation, base of operations, supply, and safety.

Timing. "To get your money's worth from spraying you have to hit the insects during the few days or weeks when they are most vulnerable to insecticides. The importance of proper *timing* can be illustrated by describing the problem that spray crews face when the spruce budworm attacks fir stands in the Northwest. Spruce budworms usually go through six larval (caterpillar) stages of development. They are most susceptible to insecticides when they are in the early stages, but at that time they are protected by the closed buds of the fir trees.

"The effective spraying period, which begins when the buds open and expose the larvae, lasts only about ten days. But it does not occur at the same time in all areas. It varies with the kind of fir attacked, the elevation, and the exposure.

"Proper timing has special significance in orchard spraying. If you spray too close to ripening time, you may find too much poison on the harvested fruit. If this happens, the law requires that the fruit be cleaned before it is sold. Cleaning costs money.

Base of Operations . . . "should be close to the land to be sprayed. If it's too far away, planes will have to carry gasoline instead of payload, and valuable hours of good spraying weather will be wasted.

"The runways should be long and smooth. One end, or both ends, should be free of obstructions. Clear away rocks and tall grass; fill in bogs and chuckholes. If a high wind comes up, you'll need to tie down the planes; provide facilities for doing it.

"You'll need equipment for loading gas and oil, a source of water, and sheds for storing chemicals. Power pumpers and mixing equipment for sprays are essential; without them you'll lose time, waste materials, and work under unnecessary handicaps. Supply is another factor that can make or break a spraying operation.

Safety Pointers . . . "Safety has to be considered at every step of the spraying operation . . . All men working around pesticides and equipment should know how dangerous the job can be . . . The pilot is the man in greatest danger, and the less contact he has with pesticides, the better . . . Do not expect him to do the work of mechanics or loaders.

"Fire is another danger in aerial spraying. Have fire extinguishers and shovels at the base, and prohibit smoking near spraying equipment.

"Place mixing and pumping units where planes can't accidentally taxi into them.

"Always read the precautions on pesticide labels. Don't let pesticide get on your skin. Change clothing and bathe as soon as you are through work, and have your working clothes washed daily. Wear waterproof clothing, including rubber or canvas gloves, a canvas helmet, and a respirator when the job calls for one. Never fly through a cloud of poison spray that you put out in previous passes over the field you are treating.

"Check regularly for spray-system leaks. Leaking pesticides can poison you, and they can play hob with wood, metal, paint, and fabric.

"Keep the plane and the spraying equipment clean and in good repair. Do not let spray residue accumulate in cockpit, cabin, or fuselage. Mechanically defective spraying equipment may interfere with the functioning of the plane. Make sure that you can get at all parts of the spray system easily. Install removable panels and inspection plates. If you're planning to handle several types of chemicals (insecticides, herbicides, and fertilizers), you'll want to be able to take out many parts for internal cleaning or for substitution of parts used for just one type of chemical.

"When things go wrong, you want to be sure you can get rid of your spray load—fast! Install a quick-tripping dump valve. . . If the tank has a big enough air vent, a 5-inch dump valve will empty 100 gallons of liquid in about 15 seconds.

Airborne End . . . "In choosing the kind of craft to hire, the main thing is to consider the job you want done. . . . What kind of country will the plane have to fly over? How big are the fields? How close are the landing strips? Can the plane carry a big enough load to hold down costs?"

Pest control jobs keep more than 6000 planes and 7000 pilots busy in this country. In general, there are four types of planes doing crop spraying.

"Light planes are well suited to most jobs in farming country. They can be bought and operated at relatively low cost, they maneuver well in tight quarters, and, in an emergency, they can be landed in pastures and roads.

"Spraying rangeland or a forest usually involves greater ferrying distances and larger acreage than spraying crops. For such a job, planes such as the twin-engine Douglas DS-3 have distinct advantages over light planes—longer range and bigger payload.

"Helicopters also have a place in the spraying picture. They are more expensive than light, fixed-wing aircraft, but sometimes they can make up for it by their ability to take off and land straight up and down, without a runway. This saves mileage and time, and makes it easier to handle small, hemmed-in fields. Other advantages are that poor flying visibility handicaps helicopters less than it does fixed-winged aircraft, and the downwash from the rotors helps to push the spray deep into the crop.

"In general, good equipment should—

1. Spray out the pesticide from the plane at a uniform rate.
2. Provide for an adjustable rate of discharge, so that crops get the right number of gallons of spray per acre.
3. Spread the liquid in as wide a swath as possible beneath the plane.
4. Avoid putting down too heavy a deposit in the center or at the edges of the spray swath.

"A spray outfit ordinarily has-

1. A tank, to hold the pesticide.

2. A pump, to move it out.
3. A piping and control system, to carry the right quantities of liquid from the tank to the boom.
4. A boom-and-nozzle assembly that atomizes the liquid—that is, breaks it up into the right-sized spray particles, so that it can be spread properly.

"If you own a plane and want to handle the spray job yourself, you can buy spraying rigs, complete, for some of the popular makes of plane. They can be removed readily.

If You're an Operator . . . "What kind of plane is best for you? A Cub or Stearman will lose you money on a forest job if it's a hundred mile run from the nearest landing strip to the spot to be sprayed. A twin engine Douglas simply isn't cut out for low-level work over tiny truck farms.

"Get versatile equipment. You want to be able to handle as many kinds of spray jobs as possible within your plane's limitations. Get equipment that can put out different types of sprays, produce droplets of different sizes, and discharge any kind of liquid at different rates.

Spray-Plane Piloting. "Many special techniques of spray-plane piloting have been developed. The trick is to lay down exactly the right dosage of pesticide with as few passes as possible. If the plane makes too many circuits, costs go up and time is wasted. If it makes too few, coverage isn't even and the pests aren't killed.

"Standard practice in spraying fairly flat, rectangular fields is to follow a grid pattern. The pilot flies back and forth across the area in parallel lines. He holds the distance between the flight lines the same as the effective swath width of the spray plane.

"Swath width depends on altitude, wind, plane, and equipment. Measuring it requires field tests. The part of a swath that receives approximately the recommended per-acre dosage of pesticide is called the effective swath.

"IF YOU'RE AN OPERATOR . . . For safety's sake, pilots should fly crosswind, and should move upwind on each successive pass so that there's no chance for the poisonous spray to blow back on the plane.

"When feasible, start the turnaround at the end of the spray run with a 45-degree climbing turn downwind, over the land adjoining the part of the field already treated. Then level off and reverse the turn 225 degrees. As you come around, orient yourself and line up for the next run. Then, with power reduced, let down to spraying height and start the new pass.

"Be sure to fly long enough on the downwind leg of the turn to allow room to complete the 225-degree swing without crowding or arriving too far upwind to start your next run. The aim is to avoid making tricky turns to get into position.

"If the 45-degree starting turn is made upwind, you may have to crowd the 225-degree turn and cross your slipstream to start the next run. This should be avoided.

"When the country is rough and the area to be sprayed is irregular in shape, the grid pattern doesn't work so well. The rule under these conditions is to fly either along the contours or downslope. Upslope flying with a heavily loaded plane is tempting fate.

"Check landmarks, hazards, and obstructions with your map before you start spraying. If adequate landmarks are lacking, flags should be put down to mark the fields or areas to be sprayed.

Spraying and the Law. "Don't neglect the legal aspects of a spraying job. Both the farmer and the operator may be liable for damage to neighboring property.

"See your insurance man before you start. He can help you avoid many of the legal entanglements that sometimes arise.

"Check State and Federal laws pertaining to agricultural aviation. Be sure your information is current. Many old laws have been changed in recent years, and new ones are continually being enacted.

"If you're an operator, you know whether there's a law in your State requiring you to provide workmen's compensation coverage. No matter what State you live in, you may be required to provide such coverage if you enter into a contract with a Federal or State agency.

"Some operators insure for property damage, chemical damage, and public liability. It not only protects them; it also helps them get contracts with smart farmers.

"With certain chemicals, consider the hazards of drift when the wind is frisky. If your work is in an area surrounded by potential lawsuits—hold it! Wait for calmer weather or it may cost you money. Even a slight wind may carry the chemicals to surrounding crops. Here's where chemical-damage insurance comes in handy.

"One of the best forms of insurance is courtesy. Take the time and trouble to let owners of adjoining property know that you're planning to spray. They can arrange to protect livestock or poultry that might be panicked by the roar of the plane, or bees that might be injured by the spray.

Where to Get More Information. "You can get pest-control information from county agents, State experiment stations, State colleges and universities, and local stations of the U. S. Department of Agriculture (for certain specialized work only).

"A number of State agricultural colleges conduct short courses in pest control, including use of aircraft. Ask the schools in your own area about this. Regional and national conferences, held annually, cover the latest developments in weed and insect control."

The Civil Aeronautics Administration's district offices are glad to help aircraft operators improve their equipment and efficiency.

"Pesticide manufacturers are up to date on pest-control problems throughout the country. Their representatives are usually eager to help operators."

For information on pesticides, herbicides, and laws, write the National Agricultural Chemicals Association, 1145 19th Street, N.W., Washington, D. C.

Write for these booklets on pesticides, organizations, and chemical equipment companies:

Entoma, Ellsworth H. Fisher, Dept. of Entomology, University of Wisconsin, Madison 6, Wisconsin.

Pesticide Handbook, P. O. Box 789, State College, Pennsylvania.

Proceedings of the Texas Agricultural Aviation Conference, College Station, Texas.

Proceedings of the Agricultural Aviation Research Conference, A.R.S., U. S. Dept. of Agriculture, Washington 25, D. C.

Read the other chapters of this book and also consult the references. Finally, you can get information on the various agricultural pests and approved control methods from the U. S. Department of Agriculture, Washington 25, D. C.

Some Equipment Facts

Tanks. " . . . Of the metals, stainless steel is best, but aluminum and galvanized iron are satisfactory for most of the pesticides commonly used. Molded plastic tanks eliminate the rust and corrosion worry, and are not attacked by the usual chemical solvents.

"Some operators build satisfactory tanks of wood, usually plywood. They treat them inside with special paints or liquid plastics to prevent leaks, and brace them rigidly to prevent bulging.

"Others use removable tank liners of synthetic rubber or plastic—a different liner for each type of spray. This cuts down cleaning time and keeps one spray from contaminating another.

"Operators who dust as well as spray sometimes build a liquid-tight dust hopper of metal, plastic, or wood. With small changes it can also be used as a spray tank.

"Keep the filler neck big! The best necks are large enough to let you pour spray liquid into the tank from a 5-gallon can or bucket without a funnel. A big neck will also give you convenient access to the tank interior for cleaning. Fit the neck with a removable fine-mesh screen to catch sediment. Put it far enough down into the tank, so it won't cause splashing or flooding. Don't put the air vent in the filler cap.

Pumps. "Some centrifugal pumps have small impellers with wide vanes—to move high volume at low pressure. Others have large-diameter impellers with narrow vanes—to move a lower volume at higher pressure. The best pump for aerial spraying is one somewhere between these two extremes.

"The big advantage of centrifugal pumps is their ability to handle all kinds of spray chemicals with minimum wear. However, they're seldom self-priming. You have to mount them lower than the tank or set up some kind of priming arrangement. Also, whereas most gear pumps go either forward or backward, centrifugal pumps push the liquid in one direction only.

TURBINE-TYPE UNITS. "Turbine-type pumps, like centrifugal units, handle all sprays without undue wear.

"The turbine type offers somewhat higher pressures, and will pump in either direction. But it has no dry lift. You have to mount the pump lower than the tank or prime it by hand.

GRAVITY-FEED SYSTEMS. "If you're handling herbicides, liquid fertilizers, or other agricultural chemicals best applied as coarse sprays, or if you're using special atomizing devices instead of standard nozzles, you may be able to skip pumps and use a gravity-feed system.

"The weight of the liquid in the spray tank creates the outlet pressure, but pressure and rate of flow will go down as you empty the tank. You can compensate for this and keep your output constant by installing a float chamber or variable orifice between the tank and the nozzles.

"Or — even simpler — vent the tank with a tube that extends through the top of the tank down through the liquid to half an inch above the bottom. The pressure of the liquid in the tank will slow the flow of air into the vacuum area created at the top of the tank as the spray goes out. This keeps the rate of discharge practically constant till the tank is emptied to below the bottom of the tube. A half-inch tube will give enough air to handle a liquid output of up to 100 g.p.m.

"With this negative-pressure vent system it is important that the filler cap be airtight. If a dump valve is installed, a separate vent in the top of the tank will have to be opened in conjunction with the dump valve.

MATERIAL. "Nonrusting metals must be used in pumps. Brass is most common, but aluminum is recommended because it's lighter. Aluminum is used more often in centrifugal and turbine pumps than in the gear types.

"Pump shafts should be brass or stainless steel. Get the mechanical type of packing seal; it lasts much longer, and needs less attention, than others.

"The stuffing-box variety of packing gland gives fairly good service, but you have to tighten it when there's a leak. Don't tighten the packing nut too hard. If you do, the packing will bind the shaft and cause excessive wear.

DRIVES. "Power sources commonly used to run a spray-plane pump include wind-driven propellers, hydraulic motors, electric motors, and the aircraft engine's accessory drive pad.

Wind-Driven Propellers. "For a windmill assembly you need a wood or metal propeller with two to six blades. An automobile fan works well, but it's dangerous unless well reinforced.

"Mount the propeller-and-pump assembly on your plane's landing-gear leg or on a sturdy bracket on the side of the fuselage, or hang it under the fuselage. With the assembly in any of these places, the slipstream from the plane's propeller gives added drive to the propeller that powers the pump.

"The best way to fasten the propeller to the pump is to couple the propeller shaft to the pump shaft with a universal joint. If you mount the propeller directly on the pump shaft, you'll need a ball-thrust bearing to carry the thrust load from the pump shaft to the pump casing. Without it, the air pressure on the propeller may damage the pump. The propeller's blade pitch will determine how fast the pump rotates.

"Put a brake on the pump assembly. Using the brake helps lengthen the life of the pump and the packing glands.

Hydraulic Motors. "Hydraulic systems work well. If your plane has a hydraulic system to operate landing gear or flaps, you may be able to tie your spray pump in with it.

"Generally, though, you're better off to install a separate system. Mount a hydraulic pump on an engine accessory pad, then couple a hydraulic motor to the spray pump. To complete the power system, you'll need these items: Hydraulic fluid reservoir (small), accumulator, pressure-relief valve, control valve, and suitable tubing.

"You can mount the spray pump entirely inside the fuselage, wherever it fits in best with the rest of the equipment.

"If you pick a hydraulically driven spray-pump system, you can start and stop the hydraulic motor by using an unloader valve in the pressure line from the hydraulic pump. Run a small line from the unloader valve to an on-off valve in the cockpit, then continue the line to the hydraulic reservoir. Opening the on-off valve cuts off the hydraulic motor and stops the spray pump. You'll also need a separate control valve for the spray flow.

"Light and powerful, this type of hydraulic system is also good for powerfeed and agitator drives in dust or baithopper installations.

Electric Motors. "Electric-motor-driven pumps have been used for aerial spray work, but usually they're too heavy in relation to power produced.

Accessory Drive Pad. "If you decide to use an accessory drive pad for power, you can mount the pump on the pad, or connect it up through pulleys or a flexible shaft. But these systems may have certain disadvantages.

✓ **Pipes and Fittings.** "Use aluminum, stainless steel, or plastic tubing. For connections, stick to dural or brass flare-type fittings, gas-and oil hose that is resistant to aromatic fuels, and good quality hose clamps.

"Get tubing that is large enough to permit the spray system to keep up with your pump's top output. Lines should have as few sharp bends as possible.

Main-Line Valves. "The valve by which you control output should be either a quick closing gate valve or a cone-type valve. Don't use a glove-type valve that takes more than one full turn to operate.

"Locate the control valve between relief valve and boom, or between pump and boom if you don't use a relief valve. Put it where you can work it with a push-pull rod, or by a cable-and-spring system. Place the control handle near the throttle. It should move forward to turn spray on and backward to turn spray off.

"If your plane has an electrical system, electrically operated solenoid valves or electric motor-operated valves are especially good. By mounting a toggle or push-button switch on your control-stick grip or control wheel, you can operate the valves with a flick of your finger, without even taking your hand off the throttle control.

Nozzle Shutoff Valves. "If nozzles are not equipped with check valves or shutoff valves, the liquid will dribble after the flow has been shut off.

"You can get nozzles that have a check valve in the body, or nozzles attached to check-valve-assemblies. Or you can have a hand-controlled shut-off valve at each nozzle. This calls for a pull cable to open each valve. The cable parallels the boom, outward from the center to the last nozzle on each side of the plane. You operate the cable from the cockpit. The valves close by spring tension when you release the cable. Another system uses a push-pull rod or tube to open and close the valves.

Other Valves. " . . . If you use a centrifugal pump, the line to the pump inlet should be as large as, or larger than, the pump's inlet port. You won't need a relief valve to unload pressure with this type of pump. However, a standard globe valve between the output side of the pump and the tank will permit some of the pump's output to be bypassed to the tank for pressure adjustment. The pump flow should be routed back to the tank when it's not flowing to the boom, in order to keep the spray liquid hydraulically agitated—an important point when you're using emulsions or suspensions.

"A three-way valve will do the job. Or use a quick-closing gate valve in conjunction with a lightly loaded relief valve or unloading valve installed between the pump and the shutoff valve. The relief line can return the pump output to the tank.

"*For Positive-displacement pump systems.* A positive-displacement pump (gear, vane, or piston pump) needs a relief valve. The relieved spray liquid is piped back to the tank near its bottom. Set a small vent line with restricting orifice between the shutoff valve and the nozzle check valves, so that you'll get immediate pressure relief in the spray boom when you close the valve. You can connect the other end of this vent line at any point in the main line between pump and tank."

Kinds of Airplanes for Spraying

UNTIL now, essentially all aircraft were designed for other than agricultural uses. Aircraft in agricultural aviation divides into three distinct areas:

1. Use of light aircraft for transportation of farmers and ranchers.
2. The use of airplane as a distinct agricultural tool to dispense chemicals. (Geuting, 1954)
3. Big multi-motored outfits like the B17 converted bomber and the cargo-carrying Douglas C47 for spraying forests and other special jobs that permit high flying over large areas.

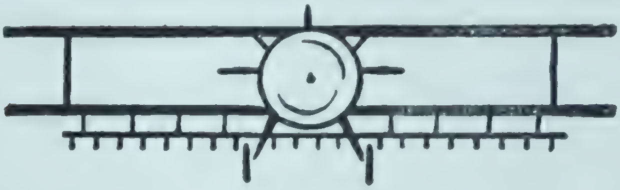
Desirable characteristics for the agricultural plane include:

1. Ability to fly at slow speed and low altitude while under positive control of the pilot.
2. Ability to carry a substantial load, sometimes a ton or more
3. Structural characteristics that would provide crash-injury protection for the pilot.
4. Unobstructed forward and downward vision. In addition, there are those characteristics for the agricultural technician to enable the machine to best dispense the compounds to be applied—bins, tanks, agitators, plumbing, nozzles, etc.

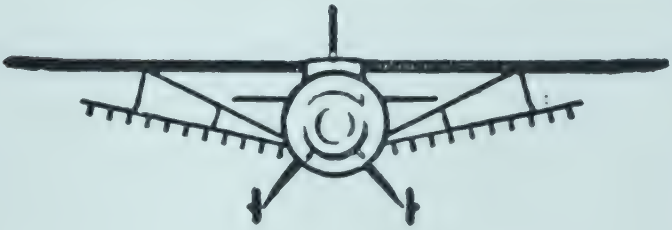
Obviously it may not be possible to combine all desirable features in the same machine because of limitations of size, cost and other factors. With spraying gaining over dusting it is likely that spraying can completely replace dusting and thereby eliminate the dust distributing apparatus so that a combination dispersing set-up can be more easily installed for applying spray, dry granules, seeds, and fertilizers.

At present the airplanes most frequently used for spraying are converted trainers of two general types, light high-wing monoplanes like the Piper cub (see Figure 116) that carry loads of 300 to 600 pounds (38 to 75 gallons) and somewhat larger biplanes like the Stearman, N3N, etc. that carry 600 to 1200 pounds (75 to 150 gallons). None were designed specifically for spraying. The multi engine converted bombers and cargo-carrying planes are in another category and will be discussed later under forest spraying.

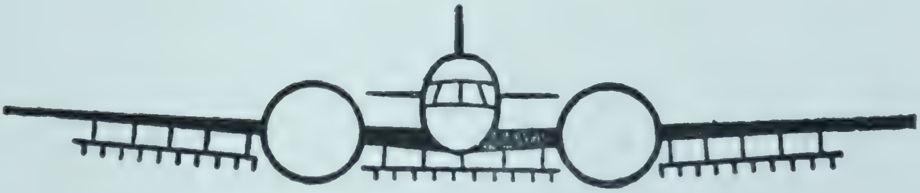
The Stearman Trainer biplane (Fig. 117) is probably the present workhorse of the aerial applicator. Aerial applicators have modified



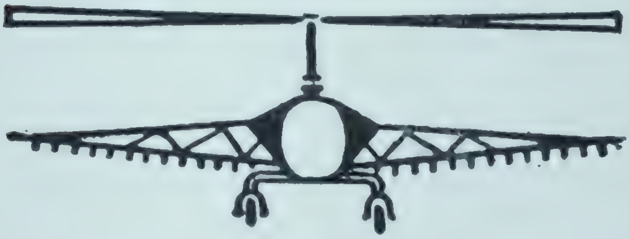
Biplanes, like the Stearman.



Monoplanes of the Cub type.



Multiengine planes, like the Douglas DC–3.



Rotary-wing craft—the helicopters.

Figure 116. Silhouettes of agricultural aircraft

it by replacing the forward cockpit with a spray tank or bin and, in some cases, replacing the original engine with one of 300 to 450 horsepower for power to climb rapidly to avoid collisions with ground objects, trees, poles, fences, and the like.

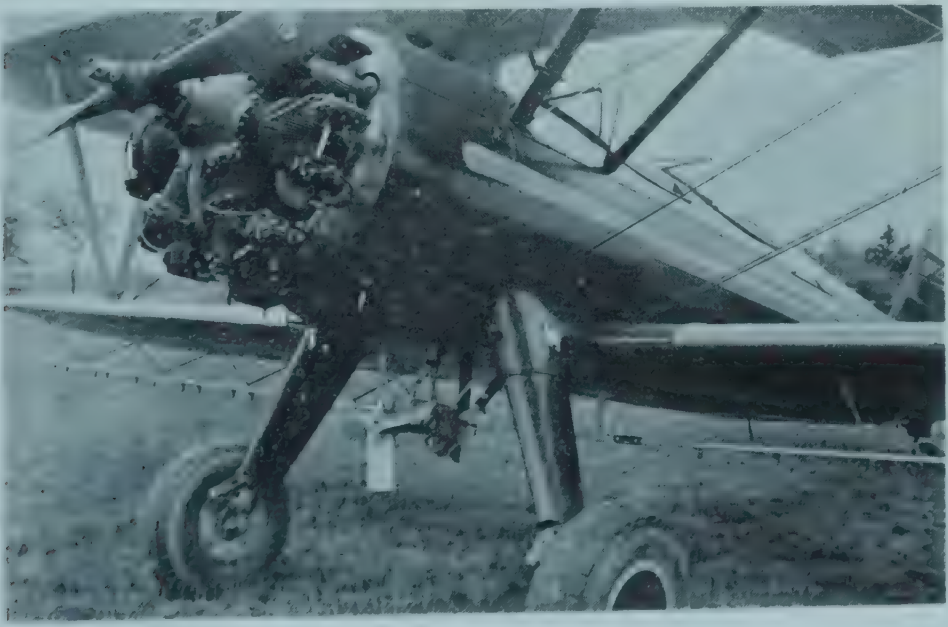
Ideally, a plane for spraying field crops probably should be a low-wing monoplane with good forward visibility for the pilot, and a high power-to-weight ratio.

Piper Aircraft has developed a modification of the Supercub—the Piper PA 18-A, featuring ease of conversion from dust to spray equipment. This airplane can be procured from the manufacturer with spray apparatus installed. A 18 cubic-foot hopper carries 1000 pounds of dust or 110 gallons of spray mixture. It dusts crops preferably at an altitude of 2 to 8 feet at 60 to 80 m.p.h. Spray may be applied at a higher altitude, up to 20 feet.

Specially Designed Airplanes. In 1949 the National Flying Farmers Association, recognizing the need for improvement in this field, initiated a project for the development of an experimental airplane especially designed for spraying, dusting, seeding, and fertilizing (Weick, 1954). It was designed and constructed by the Texas A & M Personnel Aircraft Research Center with funds

Figure 117. Stearman 2002 equipped with centrifugal pump and spray boom. June, 1947.

U.S.D.A., Series No. 87, BPI, S & Agr. Eng., Toledo P 155.



and technical aid furnished by the Civil Aeronautics Administration and with counsel from the U. S. Department of Agriculture.

The first plane built was known as Ag-1, an individual experimental ship, not intended for commercial production. It is being superceded by a number of planes that incorporate the more desirable features of the Ag-1 in varying degrees. One is designated as Ag-2 and is being developed by the Transland Co. in Los Angeles. This airplane is now being fitted with a 450-horsepower engine and is designed to carry a chemical load of 2000 pounds.

Another is the Ag 3 designed to carry a pay load of 800 pounds with a 135 horsepower engine. Both the Ag-2 and the Ag-3 have the same overall configurations including pilot-safety and field-of-view characteristics.

Two other new airplanes that are already flying are the 190-horsepower Snow low-wing monoplane duster and the Air-Tractor, built by the Central-Lamson Corp., Yakima, Washington.

With these and other developments under way, spraying operators should soon have aircraft that are designed for the job.

Research and Development Projects. Several projects are underway, including:

1. The Texas A & M Project, Personnel Aircraft Center, Box 3 F. E., College Station, Texas. Project began in 1949.
2. The "Ohio Project." School of Aviation. Columbus, Ohio. This is a cooperative effort by public and private concerns, with the first endeavor to develop a general purpose plane embodying the best knowledge of pilot safety (including wire cutters on the leading edge of the landing gear struts), carrying capacity, operation economy, and a more effective distributor. At present the "Ohio Project" is designed around the Pipers like the J3.
3. Airplane Distributing Equipment, Agr. Eng. Res. Branch. U.S.D.A., A.R.S., Box 107, Station A, Toledo, Ohio.
4. Aircraft and Special Equipment Center, A.R.S., U.S.D.A., Beltsville, Md.
5. Aircraft in Forest Insect Control. Forest Insect Laboratory, U.S. Forest Service, U.S.D.A., Beltsville, Md. Project began in 1946.
6. Agricultural Engineering Research Branch, A.R.S., U.S.D.A. Box 278. Forest Grove, Oregon.
7. Forest Insect and Disease Laboratory, U.S. Forest Service, U.S.D.A., 335 Project Street, New Haven, Conn.

Installation of Spray Equipment

USEFUL spray equipment installation for a Piper Cub J-3 airplane is outlined below by Hedden 1952) as follows:

"The equipment described below was developed in cooperation with the Bureau of Entomology and Plant Quarantine and fitted to a Piper Cub J-3 airplane used for the experimental application of sprays to field crops. Only a general description of the equipment is given and details are incomplete, as it is intended to serve solely as a guide to individuals in fitting spray equipment to the dimensions of their own airplanes. The equipment may be adapted for use on any small airplane by making the necessary changes in dimensions and shapes of parts.

"Civil Aeronautics Administration Aircraft Specification No. A-691 prescribes weight and balance limitations for several models of the Piper Cub. The specification applicable to the plane concerned should be consulted when adapting this equipment to another airplane. Paragraph 18.20-15 of Civil Aeronautics Manual 18, dated August 1, 1949 and Paragraph 2.304 of Appendix A, Civil Aeronautics Manual 8, dated January 5, 1951, as amended, should be consulted as a guide in determining weight and balance characteristics of this equipment after its installation in an airplane. If an outboard metal propeller is used to drive the pump, Paragraphs 1.33 to 1.334 inclusive of Appendix A, Civil Aeronautics Manual 8 should be carefully studied and the propeller location selected to comply with the safety regulations outlined therein. If the propeller cannot be located as prescribed, the installation should be shielded as outlined in Paragraph 1.330 of the previous reference.

Spray Tank. "The tank shown in Figure 118 has a capacity of 28 gallons. The equipment installed in a Piper Cub J-3 with 75 HP engine was licensed to carry 211 pounds or about 25 gallons of water-mixed spray. Extra volume in the tank prevents leakage during flight maneuver and provides space for the foam which often forms when sprays contain considerable emulsifying or wetting agents. The tank was made from 24-gage galvanized sheet iron. Some saving in weight could be made by using sheet aluminum. Weight of the baffle inside the tank may be reduced by making several large perforations in it. The shape of the tank bottom is such that it will drain completely in level flight or when on the ground. A filler opening of generous size is located on the right front corner of the tank. A cylindrical screen, about six inches

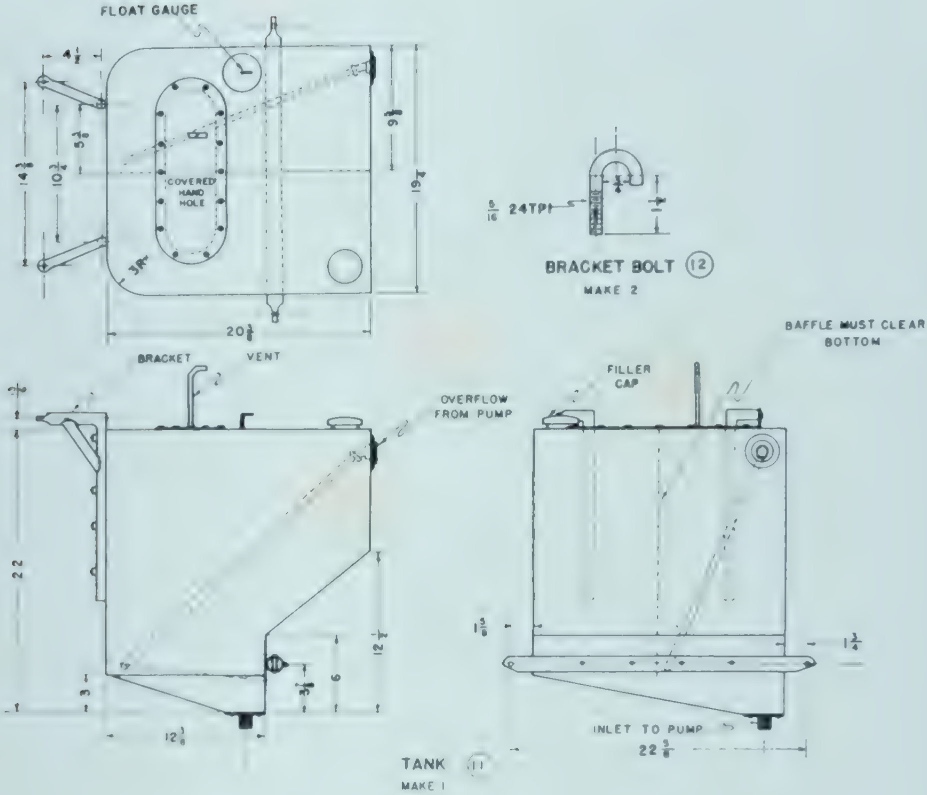

FLOAT GAUGE
4 1/2
14 3/8
10 3/4
5 1/8
COVERED HAND HOLE
3R
20 3/8
9 3/8
19 1/4
5/16 24TPI
BRACKET BOLT (12)
MAKE 2
BAFFLE MUST CLEAR BOTTOM
BRACKET
VENT
OVERFLOW FROM PUMP
FILLER CAP
22
12 1/4
6
3 1/4
3
12 3/8
1 5/8
1 3/4
INLET TO PUMP
22 3/8
TANK (11)
MAKE 1

Figure 118. Drawing of tank.

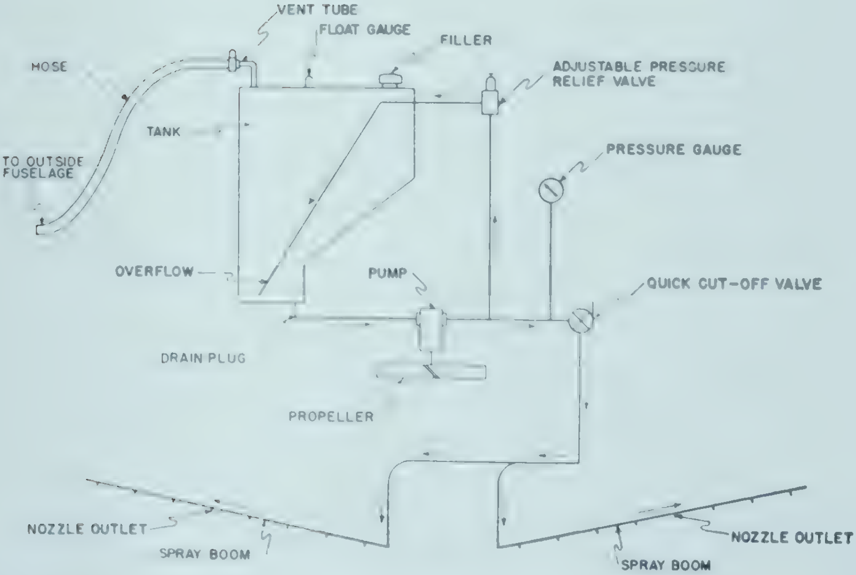

VENT TUBE
FLOAT GAUGE
FILLER
HOSE
ADJUSTABLE PRESSURE RELIEF VALVE
TANK
TO OUTSIDE FUSELAGE
PRESSURE GAUGE
OVERFLOW
PUMP
QUICK CUT-OFF VALVE
DRAIN PLUG
PROPELLER
NOZZLE OUTLET
SPRAY BOOM
NOZZLE OUTLET
SPRAY BOOM

Figure 119. Diagram of Spray Solution Circulation

long, made from 20 mesh wire cloth, was fitted into the filler neck. This screen was removable for cleaning. The vent tube (½-inch inside diameter) was extended outside the fuselage by a light rubber hose about 46 inches long. The end of the hose can be attached to the lift strut and may be adjusted in position to produce a neutral or a reduced pressure in the tank. It is thought this should not exceed 1½ inch of water when the plane is at normal flight speed with maximum delivery from the tank to spray boom. The float gauge may be an ordinary cork float properly oiled and water proofed. A large hand hole is provided for cleaning and inspection.

"Figure 119. Illustrates the return of the overflow to the bottom of the tank as a means of agitation. This also reduces foaming of spray materials.

"Rear seat, rear safety belt, and rear control stick must be removed for installation in the Cub. The tank can then be attached to the seat cross-member fittings. Bracket bolts attach the tank brackets to the tubular cross bars in the reat seat compartment."

Pump. "The vane pump used has a manufacturer's rating of 20 gallons per minute at 50 pounds per square inch with pump at 2000 r.p.m. It was directly driven by a small wooden propeller and mounted by bolting to the combination first boom stay and pump base on the left side of the fuselage.

"Gear pumps have also been mounted on this bracket. If the dimensions were altered appropriately, other types of small pumps such as a centrifugal, could be located on this base. The pump selected must be capable of delivering the maximum on this base. The pump selected must be capable of delivering the maximum required amount of material at the highest pressure desired. The table of spray delivery requirements can be used to decide on a suitable pump capacity if other maximum requirments are known. As an example, if the highest flight speed is to be 70 miles per hour and the widest swath to be sprayed is 50 feet at an application rate of 4 gallons per acre, the table shows 28.3 gallons of spray material must be delivered through the nozzles. Some material must be returned to the tank to agitate material there and provide some reserve for hydraulic slip which will increase as the pump clearances wear. A good figure to allow for this reserve would be 20 per cent. This would give 28.3 gallons plus 5.7 gallons or 34 gallons per minute as the total delivery capacity for the pump needed for these

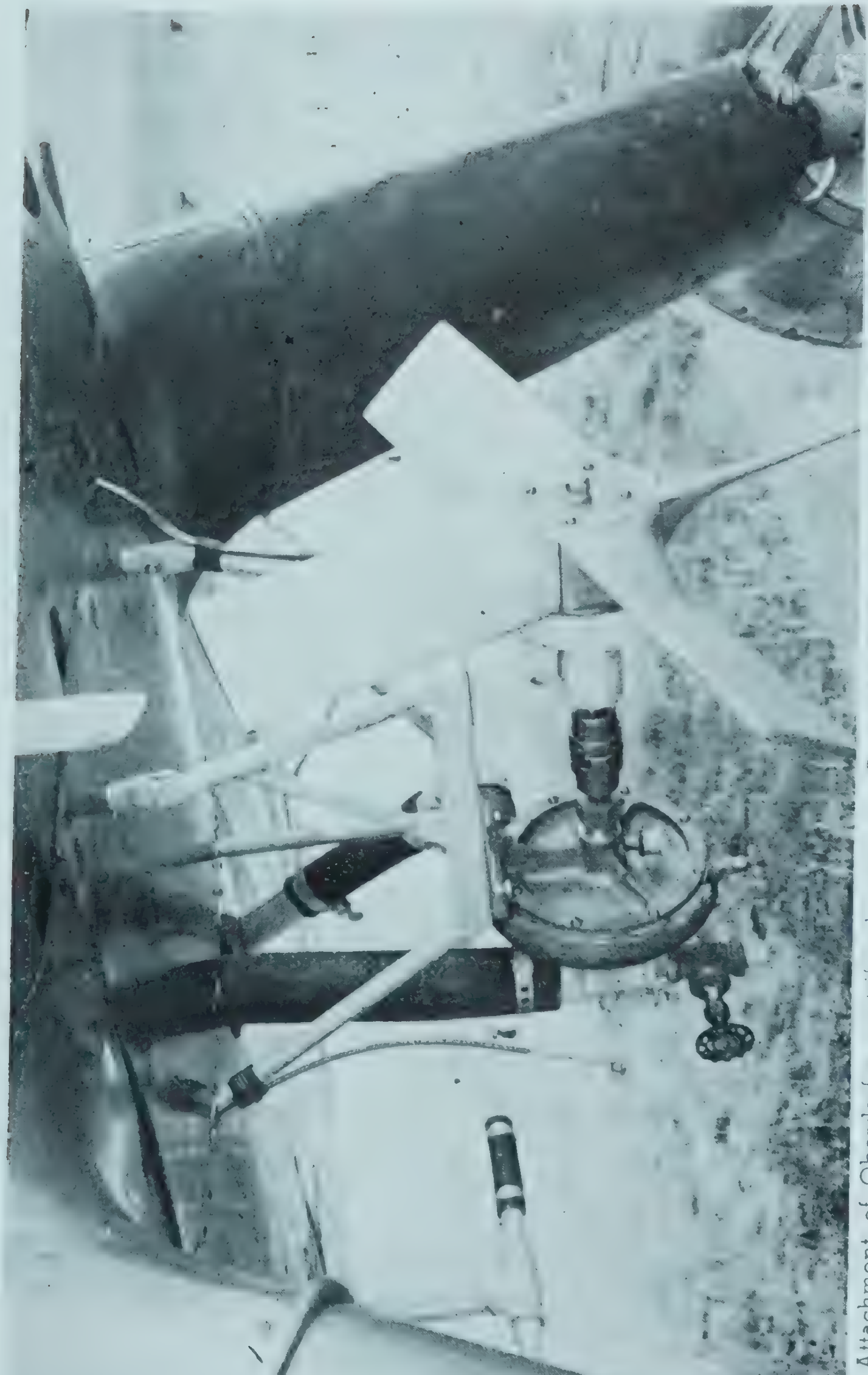


Figure 120. Attachment of Oberdorfer centrifugal pump on Stearman 2002. The emergency dump valve and tank drain valve are located in the suction line at the rear of the pump. June 1947

U.S.D.A., Series No. 87, BPI, S & Agr. Eng., Toledo P-156.

conditions. This delivery must be provided at whatever pressure the operator expects to use during the spray work. Priming troubles can be minimized by locating the spray pump in a position lower than the surface of liquid in the spray tank. The pump bearings must be able to carry the propeller thrust load when the driving propeller is mounted directly on the pump shaft. The packing gland should be kept tight and inspected frequently to be certain it does not permit leakage of toxic materials. Replacement parts and packing should be on hand for repair and servicing operations without unnecessary delay.

Propeller. "The propeller that drives the pump was made from clear, straight-grained white pine, carefully selected for freedom from small knots or imperfections. It was four-bladed and 19 inches in diameter. The blades were 3 inches wide, pitched 38 degrees and sanded smooth to remove all sharp lines on the blade faces, and edges, and at the root of the blade. Two parts were glued together by a halved joint at the center, as indicated in Figure 121. Enough material was left at the center to form a strong rigid joint. After the glueing and sanding was done, the propeller was statically balanced, and given one coat of clear shellac. When this coat was dry and sanded smooth, the blade ends were taped with 1½-inch cloth tape, using care to retain propeller balance, and a second coat of shellac was applied. The propeller was attached to the pump shaft by the hub shown in Figure 121. The dimensions given for this hub must be adapted to fit the pump used. If the end of the pump shaft is threaded and fitted with a castellated nut and cotter pin, the propeller can be easily moved for cross country travel. The propeller may be tied for short trips when pump operation in undesirable. If desired, the hub may be made longer and a small brake drum about 3½ inches in diameter machined onto it. The drum may be fitted with a 1-inch brake band actuated by a cock pit control. The pilot can then start the pump at any time while in flight and stop it when the spray tank is empty.

Boom Stays. "Four boom stays under each wing held the spray boom in place. These were made from ½ inch outside diameter, 20 gauge seamless steel tubing. It is suggested an SAE 4130 steel be used. The tube clamps which hold the spray boom were located in the center of the stay span.

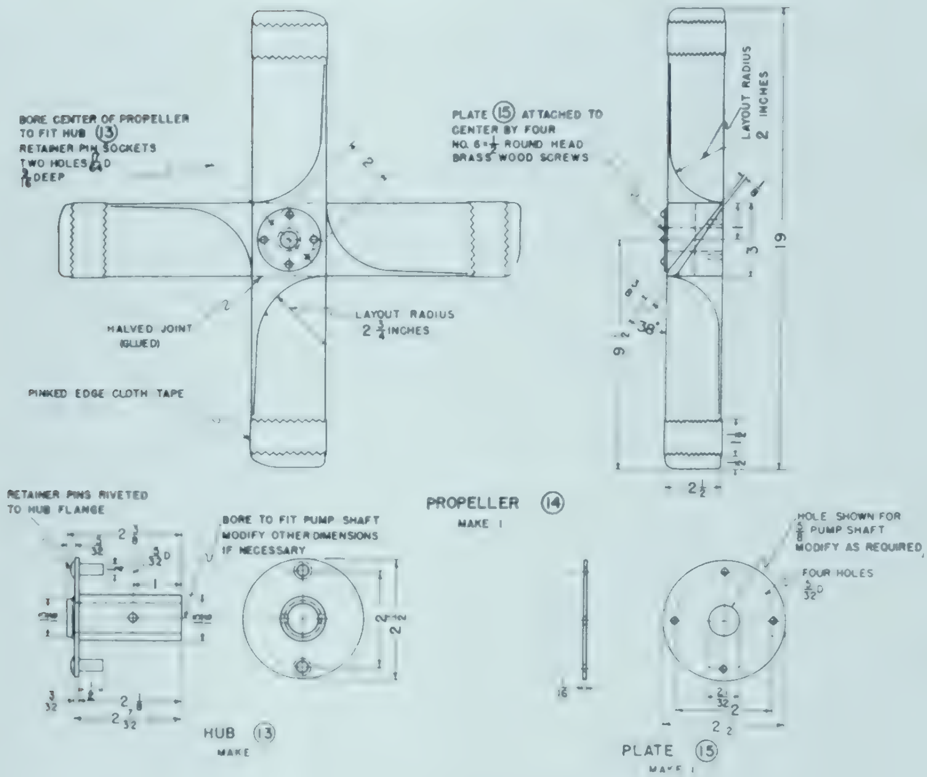

BORE CENTER OF PROPELLER
TO FIT HUB (13)
RETAINER PIN SOCKETS
TWO HOLES D
DEEP
HALVED JOINT
(GLUED)
PINKED EDGE CLOTH TAPE
LAYOUT RADIUS
2 3/4 INCHES
PLATE (15) ATTACHED TO
CENTER BY FOUR
NO. 6 × 1/2 ROUND HEAD
BRASS WOOD SCREWS
LAYOUT RADIUS
2 INCHES
19
3
38°
9 1/2
2 1/2
PROPELLER (14)
MAKE 1
RETAINER PINS RIVETED
TO HUB FLANGE
BORE TO FIT PUMP SHAFT
MODIFY OTHER DIMENSIONS
IF NECESSARY
2 3/8
2 1/8
2 7/32
HUB (13)
MAKE
HOLE SHOWN FOR
3/8 PUMP SHAFT
MODIFY AS REQUIRED
FOUR HOLES
3/32 D
2 1/2
PLATE (15)
MAKE 1

Figure 121. Propeller, Hub and Plate.

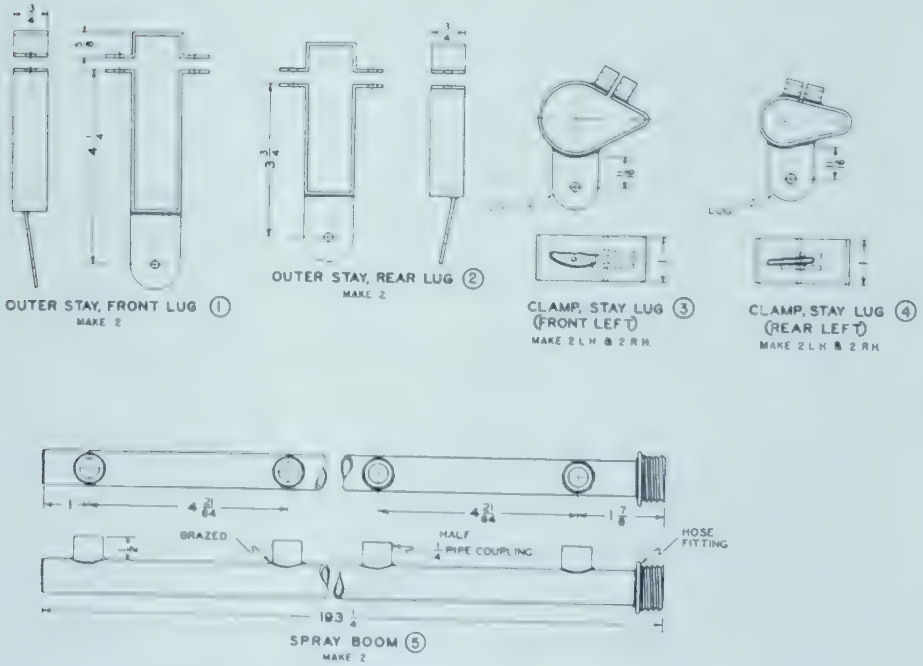

OUTER STAY, FRONT LUG (1)
MAKE 2
OUTER STAY, REAR LUG (2)
MAKE 2
CLAMP, STAY LUG (3)
(FRONT LEFT)
MAKE 2 L.H. & 2 R.H.
CLAMP, STAY LUG (4)
(REAR LEFT)
MAKE 2 L.H. & 2 R.H.
4 21/64
1 7/8
BRAZED
HALF
1/4 PIPE COUPLING
HOSE
FITTING
193 1/4
SPRAY BOOM (5)
MAKE 2

Figure 122. Clamp and Spray Boom.

"The outer boom stays attach to clamps on the wing spars in the wing tips. These stays and clamps are shown in Figure 122. In addition to the clamps shown, four clamps (two of each size) without lugs but similar to the stay lug clamps (3 and 4) shown in Figure 122 are required. These were used to clamp the first boom stays (6 and 7) to the low ends of the lift struts.

Spray Boom. "The spray boom for the plane consisted of two lengths of ¾-inch outside diameter, 18-gauge seamless-steel tubing (SAE 4130), as shown in Figure 122. Pipe couplings cut in half were brazed to each length of tube, spaced as indicated. The male hose fitting brazed to the end of each tube nearest the fuselage was a light-weight, ⅝-inch inside diameter fitting. The spray boom is clamped to the boom stays by means of pressed steel tube clamps, AN741-T6, welded to the boom stay. These clamps are a standard item sold by most aviation supply firms. The spray boom should be thoroughly tested for leaks, under pressure, before final installation on the airplane. The boom may be cleaned by flushing from the outer nozzle opening or a threaded fitting may be brazed to the outer end and plugged except when opening for cleaning.

Pressure Relief Valve. "Referring to the circulation diagram (Figure 119), a pressure-relief valve is shown in the return line from pump to spray tank. This is an adjustable, spring-loaded valve located in the cockpit where the pilot can manually set the desired spray line pressure while in flight. The valve will then automatically bypass excess fluid back to the spray tank.

Pressure Gage. "A pressure gage reading up to 100 pounds per square inch was mounted on the instrument panel where it was readily visible to the pilot at all times. It was connected between the relief valve and quick cut-off valve in the pressure line leading to the spray boom, by means of a small copper tube and tube fittings. It is suggested that as large a pressure gage (about 3-inch face) as can conveniently be fitted to the instrument panel, be used in order that true pressure may be more easily read by the pilot. Graduations of two pounds or less should give accurate pressure indications easily observed by the pilot. Gages should be calibrated at the beginning of each operating season and oftener if subject to hard usage.

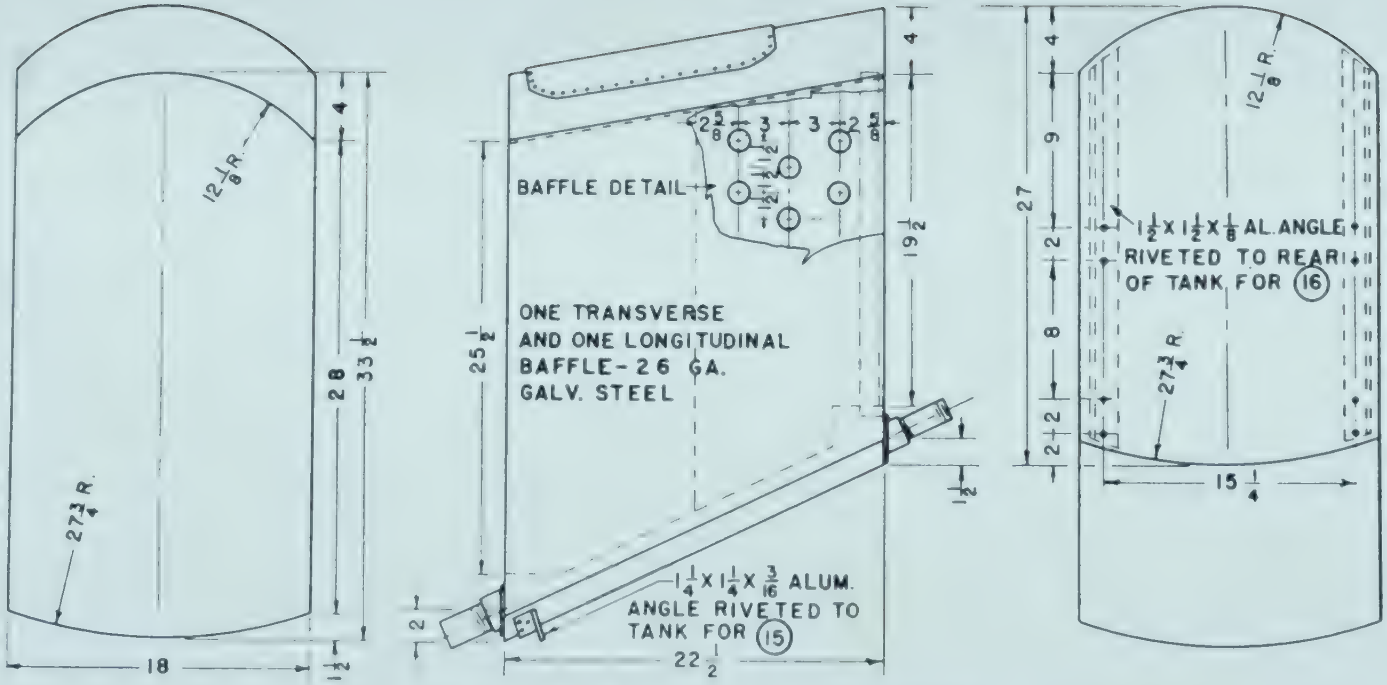

12 1/8 R.
27 3/4 R.
18
1/2
4
28
33 1/2
BAFFLE DETAIL
2 5/8
3
3
2 5/8
1 1/2
1 1/2
ONE TRANSVERSE
AND ONE LONGITUDINAL
BAFFLE-26 GA.
GALV. STEEL
25 1/2
19 1/2
4
2
1/2
1 1/4 X 1 1/4 X 3/16 ALUM.
ANGLE RIVETED TO
TANK FOR ⑮
22 1/2
27
9
2
8
2
2
1 1/2 X 1 1/2 X 1/8 AL. ANGLE
RIVETED TO REAR
OF TANK FOR ⑯
15 1/4

Figure 123 Tank for front cockpit installation.

U.S.D.A. Drawing, March, 1948

Shut-off Valve. "The shut-off valve shown in Figure 121 is a ¾-inch, quick acting type. It was clamped to the floor of the plane and connected by flexible cable, of the type used for remote throttle or heater controls, to a push-pull button located on the instrument panel."

Spray Equipment for Biplanes

The description below by Isler (1948) is offered as a guide for the installation of a boom and nozzle-type apparatus for biplanes such as Stearman or Navy N3N planes. Some modifications and improvements will be discussed later.

The apparatus consists of a tank in the front cockpit, an externally mounted wind-propelled pump, and a spray boom for nozzles mounted beneath the low wings.

Tank. "Tanks should preferably be constructed of aluminum so as to be as lightweight as possible. The tank shown in Figure 123 was constructed of galvanized sheet steel. As the equipment was used only for experimental purposes the tank was smaller than would be desirable for use in large-scale field operations. Tanks of 80 to 90 gallons capacity have been used in a Stearman by enlarging the opening in the front cockpit cowling, removing front cockpit controls and instruments, and removing the yoke from the end of the control column.

"The tank shown can be easily installed in the front cockpit by removing only the seat and front control stick. The bottom of the tank was shaped to permit complete drainage when the plane was on the ground or in flight. The cover plate in the top of the tank permits access for cleaning or making repairs. The tank filler neck and air vent were fitted to this cover plate. A fine-mesh screen-wire cylinder 10 inches long was fitted into the filler neck. The screen was removable for cleaning. The air vent was 1⅛-inch outside diameter tubing and a hose was extended from the tubing up to the upper wing. The flanges for connection of the outlet and pressure-relief bypass lines at the bottom of the tank were attached by machine screws and solder. The front flange was 1½-inch-pipe size and the one at the rear 1-inch-pipe size.

"The 1½ x 1½ x ⅛-inch aluminum angles were riveted to the inside of the tank so that the rear tank brackets, Figure 124 could be bolted to them. These brackets were then clamped to the seat posts in the front cockpit. The front end of the tank was

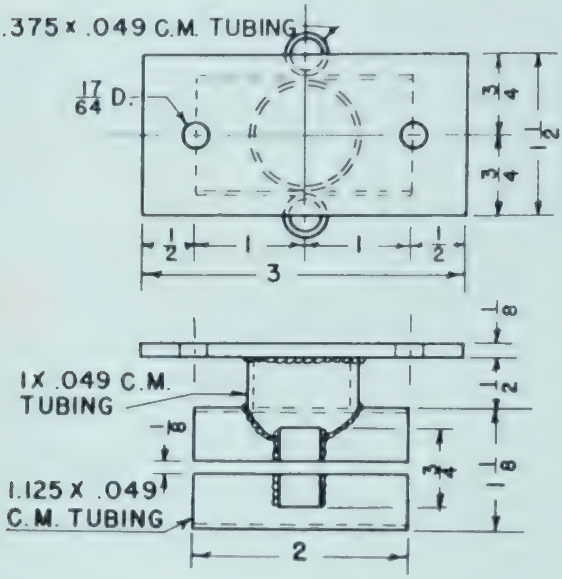

.375 x .049 C.M. TUBING
17/64 D.
3/4
1 1/2
3/4
1/2
1
1
1/2
3
1/8
1/2
1X .049 C.M. TUBING
1/8
3/4
1 1/8
1.125 X .049 C.M. TUBING
2

Figure 124. Tank Bracket Front

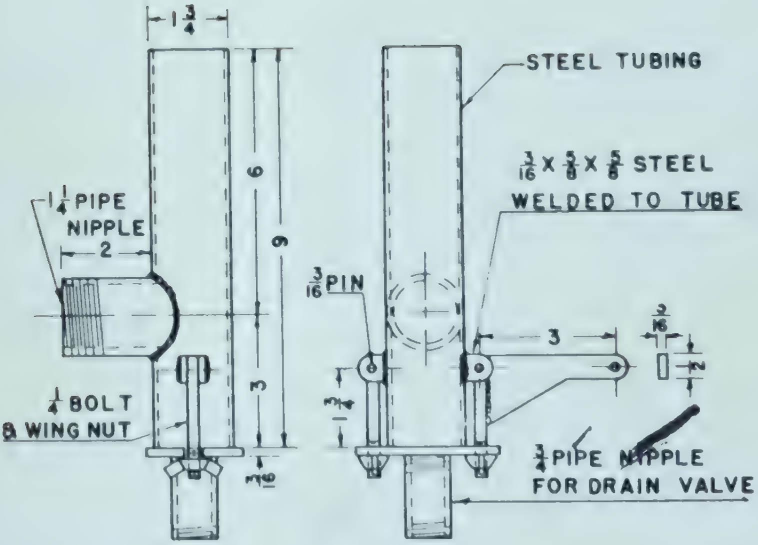

1 3/4
STEEL TUBING
6
9
3
3/16
1 1/4 PIPE NIPPLE
2
3/16 X 5/8 X 5/8 STEEL WELDED TO TUBE
3/16 PIN
3
3/16
1/2
3/4
1/4 BOLT & WING NUT
3/4 PIPE NIPPLE FOR DRAIN VALVE

Figure 125. Dump Valve Assembly.

Drawings—U.S.D.A. Bulletin, 1948

supported by front tank brackets, which were clamped around the crossmember between the lower longerons at Station 2 in the fuselage. The emergency dump-valve assembly, Figure 125, was provided with a connection for a ¾-inch drain valve. A pull-cable control was extended from the dump valve to the cockpit.

Pump. "A centrifugal pump mounted below the level of the tank was installed so that suspensions containing abrasive material could be used (page 298). The pump had 1¼-inch I.P.S. suction opening and 1-inch I.P.S. discharge opening. It was necessary to build up a special outboard bearing assembly, (see Figure 126), for this pump due to the thrust and radial load of the propeller. This pump will deliver as much as 45 gallons per minute at 25 pounds per square inch.

"A tachometer was installed on the pump shaft with a direct-reading dial in the cockpit. This installation is not essential except for test purposes. The installation of a brake on wind-driven propellers prevents wear of pump parts when not spraying and permits stopping the pump in case of breakdowns.

"Details of the pump support, may be varied to fit other makes or types of pumps.

"One-inch aluminum pipe was used to make up the line from the pump to the point of connection with the boom. Aromatic resistant gasoline and oil hose should be used for all rubber hose connections.

Spray Booms. "A 1-inch tee was fitted to the low end of the aluminum pipe extending down through the fuselage to the boom. The boom hose nipples (Figure 127) were screwed into the ends of the tee and connected with hose to the boom pipes. The spray booms, (Figure 127), were 1-inch chrome molybdenum .049 gage tubing. Round tubing was used to permit rotating the boom so that the position of the nozzle orifices in relation to the air stream could be varied. The 4¼-inch spacing for nozzle connections permitted 82 openings. When nozzles with a comparatively high discharge rate are used, the unused openings are plugged.

"The boom pipes were located about nine inches below the lower surface of the lower wings approximately midway between front and rear wing spars. Boom stay brackets were attached to the ends of the compression ribs adjacent to the wing spars.

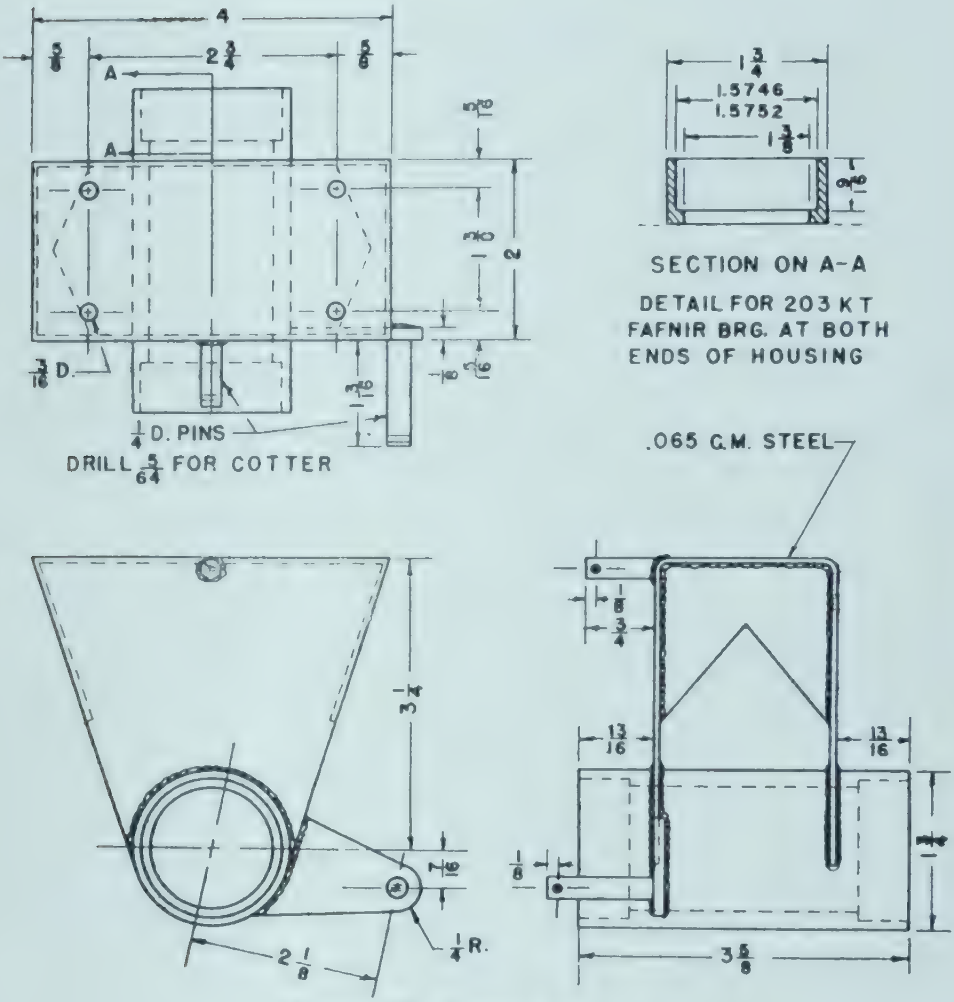
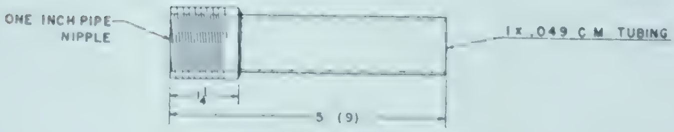
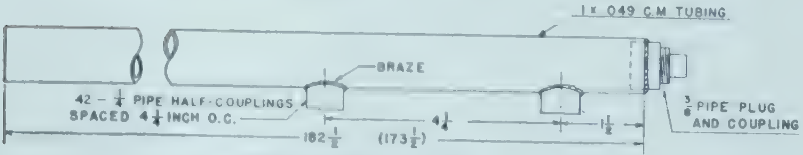

4
5/8
2 3/4
5/8
A
A
5/16
3/8
2
3/16 D.
1/8
5/16
3/16
1/4 D. PINS
DRILL 5/64 FOR COTTER
1 3/4
1.5746
1.5752
1 3/8
9/16
SECTION ON A-A
DETAIL FOR 203 KT
FAFNIR BRG. AT BOTH
ENDS OF HOUSING
.065 G.M. STEEL
1/8
3/4
13/16
13/16
1/8
1 1/4
3 5/8
3 1/4
7/16
1/4 R.
2 1/8

Figure 126. Bearing Housing


ONE INCH PIPE
NIPPLE
1 x .049 G.M. TUBING
1 1/4
5 (9)

BOOM HOSE NIPPLE — ⑫

MAKE (1) R.H. AND (1) L.H.—R.H. SHOWN—MAKE L.H. 9 INCHES LONG


1 x .049 G.M. TUBING
BRAZE
42 – 1/4 PIPE HALF-COUPLINGS
SPACED 4 1/4 INCH O.C.
182 1/2
(173 1/2)
4 1/4
1 1/2
3/8 PIPE PLUG
AND COUPLING

SPRAY BOOM — ⑬

MAKE (1) R.H. AND (1) L.H.— R.H. SHOWN

MAKE L.H. 173½ INCH. LONG

Figure 127. Spray Booms

Drawings—U.S.D.A. Bulletin, 1948

Spray Shut-off Valve and Pressure Gauge. "The spray shut-off valve, (36) Figure 126, is the common lever type cam-action quick-opening gate valve. This type valve provides a straight-through full-area opening. It should be the same size as the pump discharge line so as not to restrict flow.

"The pressure gauge, (33) Figure 128, is installed in the cockpit and connected with ¼-inch flexible tubing to the pressure line between the pump and spray shut-off valve. Any hydraulic pressure gauge of 0 to 60- pound range, with a dial about 2½ inches in diameter, is satisfactory.

"A handy bronze hydraulic pressure relief valve was installed to regulate pressure and to return the excess liquid back into the tank.

Controls. "Controls must be located so they are readily accessible to the pilot. The spray shut-off valve lever and brake-control lever, parts 18 and 19, (Figure 128), are located immediately forward of the throttle on the left side of the cockpit. The details of fabrication of the controls are shown (Figure 128). For the brake the linkage between part 22 and the tension spring was a curved piece of flat metal, so that as the top end of part 22 is turned up past center the brake is automatically held in the engaged position.

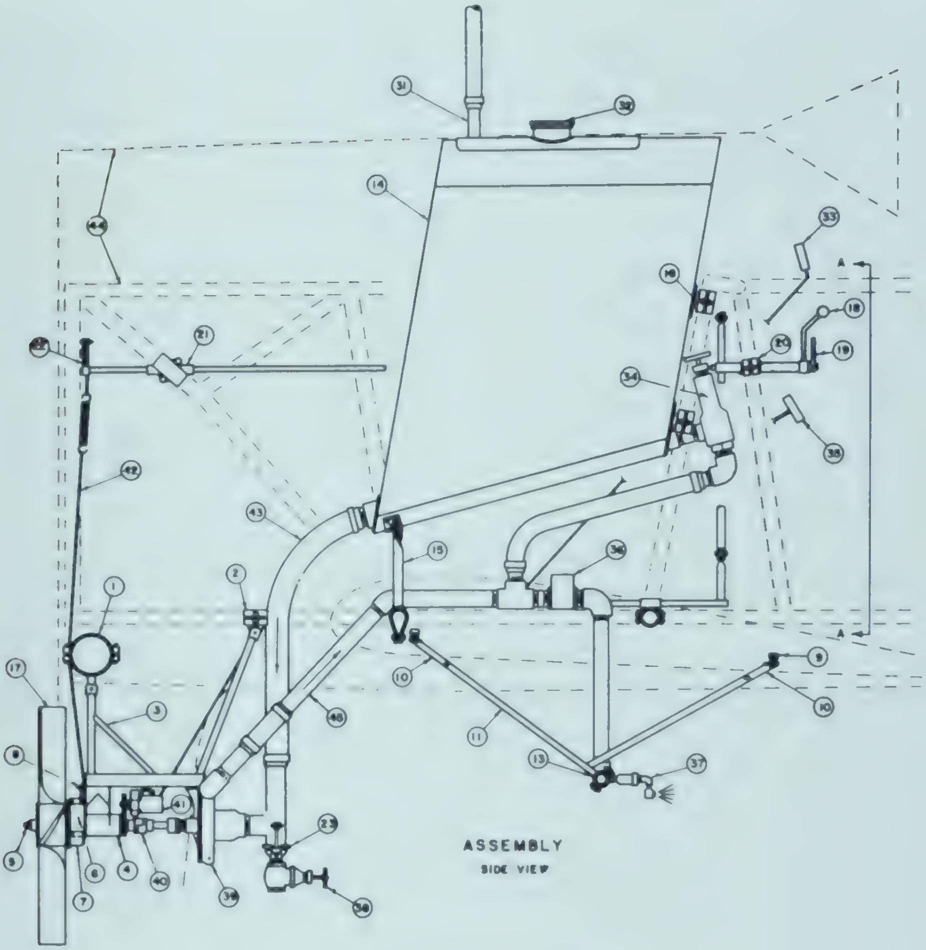
General. "All alterations and additions to aircraft must be made in accordance with instructions in CAA Manual 18. The work must be done under supervision of and certified by a licensed aircraft and engine mechanic and all installations must be inspected and approved by an authorized CAA inspector. It is advisable to contact the local inspector before work of converting to a spraying plane is started. He can advise regarding the gross weight and center of gravity limitations."

N2S Airplane Installation

An installation for the N2S airplane is described in part as follows. (U.S.D.A., EC-2, 1948).

A tank of 70-gallon capacity is installed in the front cockpit. An emergency dump valve with remote control to the rear cockpit is installed in the tank outlet.

The pump is a 1¼-by 1-inch centrifugal type, which permits the use of suspensions and emulsions, as well as solutions. It is suspended beneath the center of the fuselage, to the rear of the landing-gear assembly. It is wind-driven by a 4-bladed wood propeller 20 inches in diameter, mounted on the end of the pump shaft. The pitch



Parts Identification

1-3 Pump support and clamps
4,5 Shaft & bearing housing
6,7 Brake band & drum
8 Boom stay
9 Bracket cap
10 Boom stay bracket
12,13 Spray boom assembly
14 Tank
15,16 Tank brackets
17 Propeller
18-22 Pumb brake and spray valve controls
23 Dump valve assembly
31 Tank vent
32 Filler cap
33 Pressure gauge
34 Pressure regulator
35 Tachometer dial
36 Spray shut-off valve
37 Check valve, street elbow, & nozzle
38 Drain valve
39 Pump
40 Flexible coupling
41 Tachometer
42 Brake cable
43 Hose line and clamps
44 Fuselage frame and cowling
45 Aluminum pipe—one inch

Figure 128. Stearman 2002 Assembly.

of the propeller blades is 33-½ degrees. A small brake drum with an external brake band is fitted on the pump shaft directly behind the driving propeller. A brake-control cable extends to the instrument panel in the rear cockpit.

The spray-control valve is of the quick-opening cam-action type. An adjustable hydraulic-pressure relief valve is connected to the pump discharge line between the pump and the spray-control valve. This relief valve is located so that the hand wheel for pressure adjustment is readily accessible to the pilot. The discharge from this valve is conducted back to the bottom of the tank to provide agitation, which is necessary when suspensions or emulsions are used. Submerging the outlet of the discharge line from the pressure-relief valve minimizes foaming of emulsions and suspensions.

A pressure gauge is installed in the rear cockpit and connected by flexible copper tubing to the pump discharge line. The pump is fitted with a tachometer, with an indicating dial located in the rear cockpit.

The speed of the pump is approximately 3800 r.p.m., and it operates at a maximum pressure of about 30 p.s.i. (pounds per square inch). The maximum output at this pressure is 30 gallons per minute. With an output of 50 gallons per minute the pressure drops to 25 pounds. When the spray valve is closed, the spray liquid is by-passed through the pressure-relief valve for agitation. When the spray valve is open, only that portion of the pump output which is not discharged through the nozzles is bypassed to the tank.

Spinner Disk Distributor

THE spinner-disk assembly is described in USDA, EC-2 (1948) as follows: "It provides a means of dispersing heavy suspensions and emulsions which may have abrasive or other characteristics that prevent their use in any type of spray-nozzle assembly. The apparatus described below was installed in 1944 on a White Standard biplane, owned and operated by the Gypsy Moth Control Division of the U.S.D.A. It consists of a 110-gallon aluminum tank mounted in the front cockpit; a 2-inch pipe line extending from the tank outlet to the center of a 2-inch cross boom which is attached to the lower longerons at the rear of the pilot's cockpit; an insecticide-distributing assembly mounted at each end of the cross boom; and gauges and operational controls mounted in the rear cockpit readily accessible to the pilot.

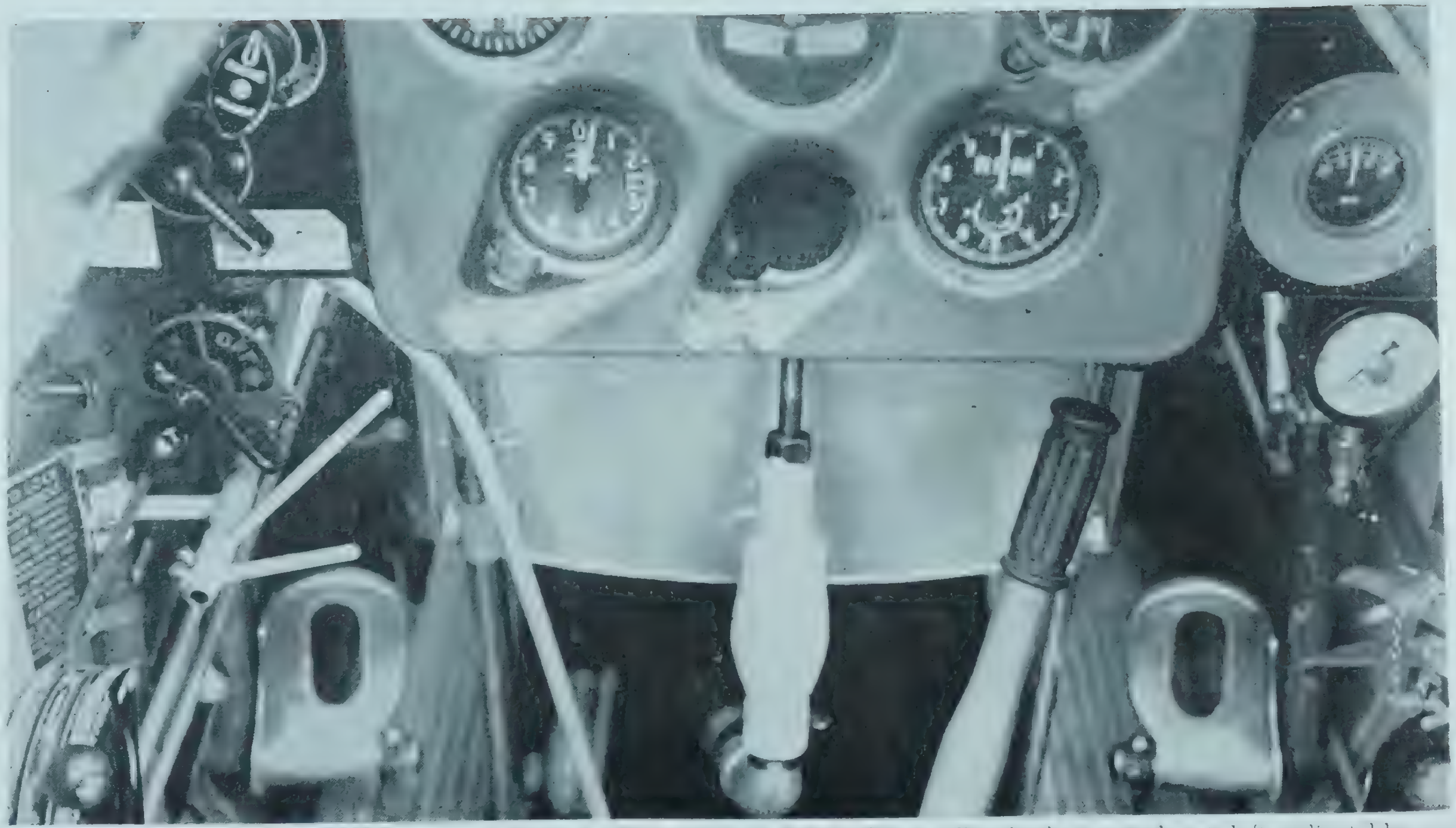


Figure 129. Interior of cockpit of Stearman 2002 showing spray valve and propeller brake controls at left, adjustable pressure regulator at lower center, and pressure gauge and dump valve control at right. June 1947.

USDA, Series No. 87, PPI, S & Agr. Eng., Toledo P-152.

"On the forward end of each insecticide-distributing assembly is mounted a 6-bladed fan connected by a steel shaft about 18 inches in length to two 14-inch-diameter, concave steel disks spaced ⅛ inch apart, mounted at the rear of the assembly. (See diagram). Power to rotate the insecticide-dispersing units (located outside of the slip stream, 6 feet from the fuselage) is derived from the forward motion of the aircraft. Both units are equipped with brakes so constructed that they can be operated by a single lever mounted in the pilot's cockpit.

When the airplane is flying at approximately 80 m.p.h. these dispersing units rotate at about 2500 r.p.m. The insecticide flows by gravity from the tank, to the rear bearing housing of the distributing unit, into a 2-⅝-inch diameter cavity in the center of the disks. It then flows onto and spreads thinly over the concave surfaces of the disks. By centrifugal force it is thrown or sprayed onto the surrounding air from the peripheries of the disks. The air blast resulting from the forward movement of the aircraft further breaks up the liquid insecticide that has thus been released. Valves controlling the rate of flow of the insecticide are located in the distributing heads close to the spinner-disk assembly, where they prevent drooling when the flow of liquid is cut off.

"The apparatus has effectively dispersed DDT, lead arsenate, and cryolite in concentrated form. Since it does not depend on pressure pumps or nozzles, it can be used for almost any liquid that will readily flow by gravity. It is a relatively expensive installation, however, because of the special machining required in the construction of the high-speed dispersing units. Another disadvantage is that, because constant pressure on the insecticide is not maintained, the flow rate is not uniform. For the dispersal of insecticides now most commonly used, therefore, other types of mechanisms perhaps have greater merit."

In the future the spinner disks would seem to be more limited to the distribution of large volumes of heavy, coarse materials like fertilizer mixtures.

Other Spraying Devices

SEVERAL types of assemblies might be mentioned for their historical and possible practical value, including centrifiugal spinning brushes with and without screens, spinning screens, and perforated collars and drums, breaker-bar sprayer (Husman, Longcoy, and Hensley, 1946), gravity flow equipment for dispersing insecti-

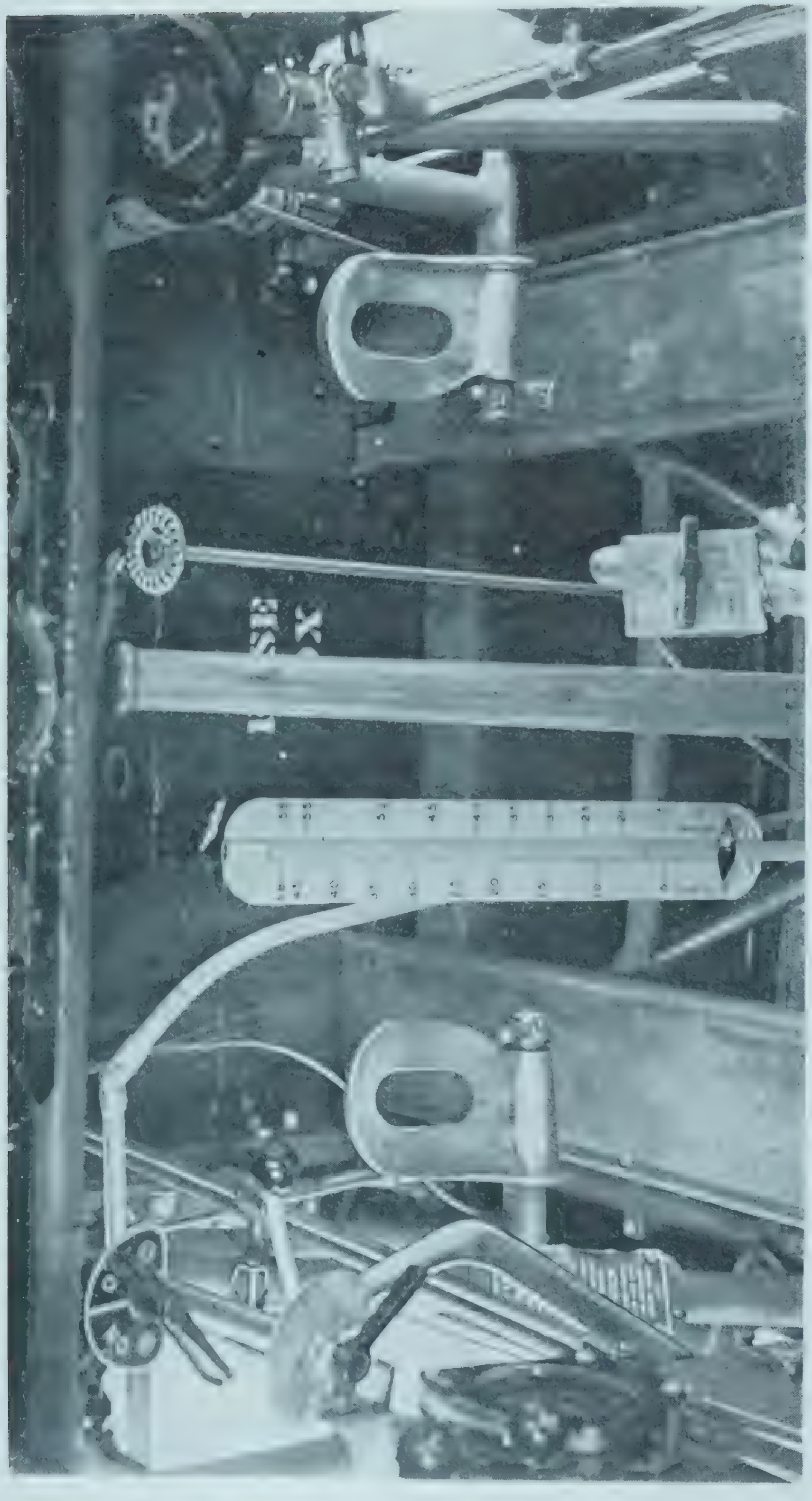


Figure 130. Interior of front cockpit showing spray and pump brake control levers at left, liquid level gauge at left of control stick, pressure regulator control emergency dump valve control, and tank vent pipe at right of control stick. Pressure gauge is in instrument panel. Stearman 3207. April 1947.

USDA, Series No. 87, BPI, S & Agr. Eng., Toledo, P-152.

cides (Faulkner, Deonier, and Davis, 1950), bomb shackle assembly (Faulkner, and Deonier, 1948); atomization by: wing tip nozzle assembly (U.S.D.A. EC-2, 1948), vibrating nozzles*; by series of 1 to 4 boom pipes with ⅛ to ¼ inch holes or with hollow tubes placed inside and outside of the propeller slip stream*; compressed air to discharge liquid at given pressure*; wet-dust, spray-dust, oil dusts*; and thermal aerosol-spray equipment.

From 1938 to 1942 several thousand acres of forests were treated with a well designed spray-dust unit constructed by William Campbell and A. G. Galloway in which an attempt was made to coat arsenicals and cryolite with adhesive solutions like fish oil. The system was not very practical for aircraft and was discarded at the end of the 1942 season. These results also confirmed the author's preliminary work in 1928 to 1935 as to the practicability of this method of application.

The early thermal aerosol apparatus consisted of a venturi within the extension of the exhaust pipe. Spray solution was injected through several small orifices placed at or near the constriction of the venturi. Rapid flow of hot exhaust gases at the point of constriction of the venturi atomizes the solution into fine droplets to make a dense, spectacular cloud. However the method is highly inefficient and ineffective due to the small drop size and lack of deposit. When all particles are of smoke size there is essentially no deposit.

Installation for Multi-engine Planes

A C-47 (Douglas) airplane has been equipped for the dispersal of DDT-oil solution in the control of gypsy moths. (see U.S.D.A. EC-2, 1948). The installation consists of two 460-gallon aluminum, rubber-lined tanks, a pump, and underwing spray booms. Two-inch pipes conduct the insecticide from the tanks to quick opening gate valves. Between the gate valves is a T leading into a 2½-inch line, which leads to the pump. From the pump a 2-inch line carries the liquid to another T, which connects to two 1½-inch aircraft aromatic-resistant hoses inside the center sections of the wings. The outer ends of these hose sections extend down through the lower surfaces of the wings, making connection with the spray booms. The tanks are placed one in front of the other, 42 inches apart, in the forward end of the fuselage. The pump, which is

---

*Unpublished notes of the author (1928 to 1935).

Table 57. Useful Data on Aircraft

(From Handbook of Agricultural Pest Control, 1951, p. 112)

Type	Horse-Power	Usual maximum pay load	Average operational speed m.p.h.	Usual height above plants, feet	Acres treated per hr. (Varies with speed payload etc.)	Approximate effective swath width, feet (varies with height, type of operation, etc.)	
		Spray gallons				Dust	Spray
Aeronca, Luscomb Piper cub, and Taylor craft	65-90	30-40	50-70	4-10	30-70	40	40-100
A.S.O. Waco	220	50-80	70-80	4-10	150	40	50+
Stearman (many types)	220-450	60-160	85-100	4-15	80+	50-70	40-120
Stinson and N3N		similar to above for the Stearman					40-80
Travalaire	220	50-80	70-80	4-10		40	50
Military types: C47 R4D, DC3., B17	2400	300-1000	90-150	100-200	1000+	not practical	80-1000
Bell Aircraft Helicopter 47D1	178	50-60	10-60	4-20	60+	60	50+
United Helicopters Inc. Hiller 360	178	60-65	10-60	4-20	60+	60	60
Kaman Aircraft Corp. Helicopter K 190	225	60-80	4-20	10-60	60+	60-70	60

powered by a 9.2-h.p., air-cooled gasoline engine connected directly to it, is placed in the aft end of the fuselage. The pump is a 2 inch capacity of 200 g.p.m. At a nozzle pressure of 25 p.s.i. its capacity is approximately 160 g.p.m. At 40 p.s.i. its capacity drops to approximately 120 g.p.m. The booms are of streamlined steel tubing of 2-inch nominal size. Each is approximately 24 feet long and extends from a point 17 feet from the center line of the fuselage outward to about 6½ feet from the wing tips. They are suspended approximately 12 inches below the underwing surface one third of the distance forward from the trailing edge of the wings. Each boom is equipped with 18 high delivery nozzle openings, some of which may be plugged to regulate the discharge rate. The airplane operates at a speed of approximately 150 m.p.h. about 150 feet above the forest canopy.

Pump and Swath Requirements for High Gallonage

WE are rapidly approaching the era when larger volumes per acre of certain agricultural chemicals will be applied in medium to large loads. The aircraft will have flying characteristics that permit bringing the loading facilities close to the area to be treated. This will permit chemicals like fertilizers and nutrients to be applied in large volumes per acre at reasonable costs. These planes must be equipped to apply 5 to 20 gallons per acre (Table 57) at 50 to 200 gallons per minute. To deliver this large volume it will be necessary to increase the number of air driven pumps to 2 or 3 and possibly increase the size of the pumps, also; or take power directly from the aircraft's engine; or install an auxiliary engine to drive one or more large pumps, or use gravity flow distributors.

The installation of an auxiliary engine should be made only as a last resort. With any given pump the maximum output can be obtained by reducing pump pressure to the minimum required for adequate atomization. This may be as low as 15 to 20 p.s.i. for coarse sprays.

It is in the high-gallons-per-acre applications that aircraft will have to compete at a disadvantage with ground concentrate equipment, both mist blower and non blower types. For example, a 30 h.p. mist blower treated 250 acres in one day at one gallon per acre. When 10 gallons per acre were applied it still took only two days. On the other hand an airplane takes 5 to 8 times as long to apply

10 gallons per acre as for the one-gallon rate, and the cost-per-acre is also several times as great for the higher gallonage.

Forest Spraying With Stearmans, N3N, and Similar Planes

WHEN an extensive area of several thousand acres is to be treated, the application of spray usually is contracted to the commercial operator offering the lowest bid for the work. For a smaller area it may be more satisfactory to employ a reliable local operator without the formality of a contract. In either case, however, the success of the operation depends largely on careful planning. In forest spraying there are innumerable details that vary with different conditions, all of which must be anticipated for efficient execution of the program. A few of the more important ones are described below, others will become apparent as the work is planned. (Yuill, Eaton, and Isler, 1951). Spraying for forest pest control has been well presented in the above paper as follows:

Selecting a Base of Operations

"IN selecting an airfield or landing strip, consider the distance to the area to be treated; the length, width, and distance of the runways; and the servicing facilities.

"The maximum practical ferry distance between the landing strip and the area to be treated will depend on the operating range of the aircraft and, in any case, the shorter the distance the better. Much valuable time can be lost and the cost of the operation increased by long ferry trips. In some cases it may even prove practical to construct temporary landing strips within or near such areas to reduce ferry time.

"The length of runways required will depend on the type of plane to be used. For the light biplanes the minimum length is approximately 800 feet. In the higher altitudes, during hot, humid weather or on a soft surface, however, longer runways are necessary. Runway surfaces should be smooth enough to permit driving an automobile over them at 40 miles per hour.

"Facilities for rapidly servicing the planes should be provided at the airfield. If not already available, aviation gasoline of the proper octane rating should be brought in. It may be dispensed from drums or a tank mounted on a truck. A suitable hand-operated or small engine-driven pump will greatly simplify loading the gasoline in the airplane. When a gasoline engine-driven pump is used, however, care must be taken never to permit the exhaust to be directed toward open drums. A fire extinguisher should be handy at all times. If gasoline drums or tanks contain sediment or water, the gasoline can be strained through a chamois-lined funnel while it is being pumped into the plane. The spray liquid may also be carried in drums or tanks on a truck and pumped directly into the plane.

Subdividing and Marking of Treatment Areas.

"IN large forested areas the portion to be sprayed is usually divided into units that can be treated in 1 to 3 days. If the area to be treated is broken by uninfested forest types or cultivated areas, it is divided into still smaller units. Sometimes these units can be laid out in rectangular shape. However, it is generally more practical to use ridges, water courses, roads, and other features of the terrain as the unit boundaries. Large-scale topographic maps, aerial photos, and aerial mosaics are particularly helpful in this connection. If possible the pilot or chief pilot in charge of flying operations should be consulted when the treating units are marked out on the maps.

"On many spraying operations markers are used to aid the pilot in locating the various treating units and in maintaining an accurate flight pattern. These markers may consist of white or orange flags, small wind socks, or light-colored feed sacks stuffed with brush; and they may be placed in the tops of trees or raised on sectional magnesium poles. In stands of relatively short timber the usual practice has been to climb the trees and rope or wire the markers in place. A recent interesting innovation in the West, where the height of the trees made climbing impractical, was the employment of a line-throwing shoulder gun to pass a light cord over the top of a tall tree to be used as a marker. A flag or paint bomb was then hauled up on the cord to mark the location.

"On large units the markers are spaced at predetermined intervals along two opposite sides of a unit, and the pilot is instructed to apply the required number of swaths between them. Where roads or trails occur along one or two sides of a unit, a small captive meteorological balloon is used to mark each spray flight line. Here, the balloon, inflated with helium or hydrogen and attached to a light cord, is allowed to rise about 40 feet above the canopy. The pilot flies directly over the balloon, which is then moved one swath width along the boundary and another spray run is made over it. This procedure minimizes application errors, but can be employed only where continuous openings in the canopy allow the ground crew to move the balloon quickly along the boundary. For spraying plantations colored cloth panels on bamboo poles can be substituted for the balloons. Smoke flares have also been tried, but are not recommended where they might create fire hazards.

Communications

"WHENEVER possible some means of communication between the airfield, the treating area, and the pilot should be provided during the spraying. This should be done because, even with the most careful planning, unexpected situations that require changes in procedures always arise during actual spray operations. A radio telephone is probably the most satisfactory solution of this problem. Although most spray planes do not have radio equipment, with a proper ground set at the treating area and another at the airfield, information or instructions can be relayed as necessary. When these ground sets are not available, local telephone services may be such that a field telephone can be installed in or near the treating area and at the airfield.

"If neither radio nor telephone is available, a system of signals may be used. One such signal system that has been satisfactory is to place a truck in an open spot visible from the air, and adjacent to or within the area being treated. When a white cloth panel is placed on the truck cab, the pilot will apply the spray as previously planned. When an orange panel is displayed, he will return to the airfield for instructions. If neither panel is shown, he will circle the area until one or the other is displayed. This system can be varied at will, but to avoid confusion the number of signals should be kept at a minimum.

"On certain large spray operations in the West it has not been possible to have ground personnel in each unit or block being treated. Under such conditions there has been little need for ground-to-air communication. However, even then telephone or radio communications between headquarters and outlying landing strips have been helpful.

Pattern and Altitude of Flight

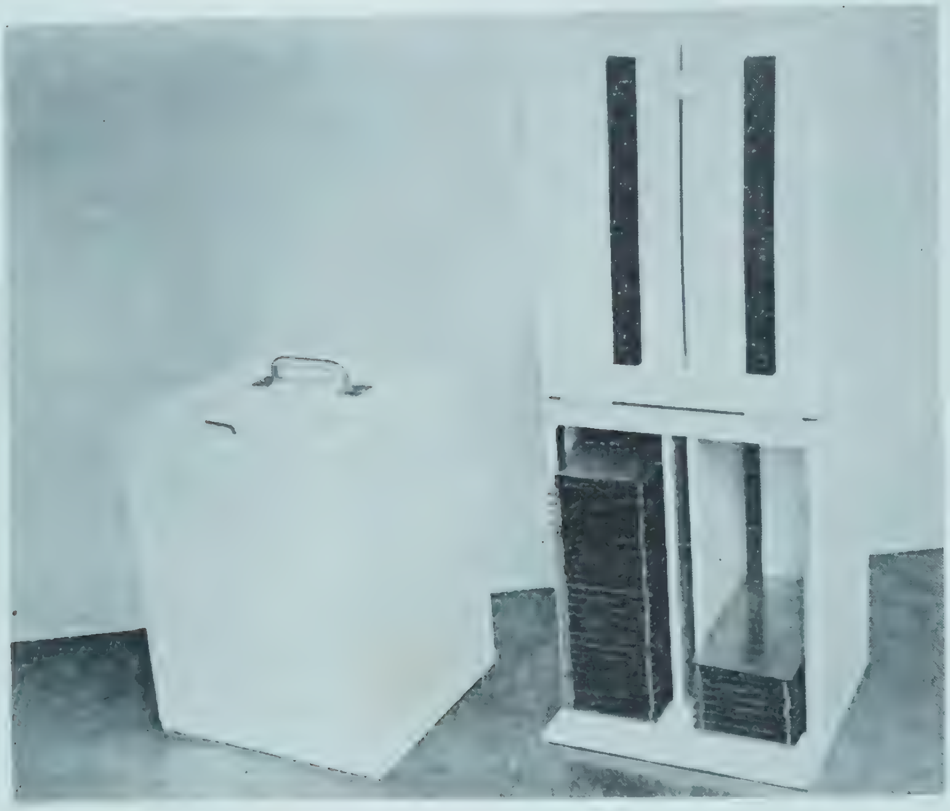
"THE flight pattern to employ in applying the spray is governed primarily by the shape and topography of the unit being treated. Where the unit is approximately rectangular and the topography is flat, the grid type of pattern is usually the most satisfactory. This pattern requires the pilot to fly in parallel lines back and forth across the unit from one side to the other, the distance between the flight lines being the same as the effective swath width of the spray plane.

"Where the spray unit is irregular in shape and the terrain is steep, flights should be made along the contours or down slope. It is not safe to fly up slope, especially with a heavily loaded plane at high altitudes. It is very difficult to obtain a uniform coverage of forests in such areas. Chances for error in spacing the flight lines are greater and, since the direction of the lines changes with the topography, it is possible that the pilot will leave some spots untreated while giving others a double treatment. The chance of this happening may be so strong in some cases that it will be advisable to increase the rate of application by reducing the distance between flight lines.

"With light planes it is desirable to apply the spray from an altitude of approximately 50 feet above the treetops in order to obtain the maximum swath width without excessive loss of spray by drift. For safety, however, the altitude must be increased when there are obstructions such as snags, where the terrain is rough, or when larger planes are used. With fixed-wing aircraft spraying should never be done at less than 50 feet above the treetops. A qualified pilot will know the performance characteristics of his plane and the limitations imposed by topography, elevation, and associated air conditions.

Observations During Spraying

"WHILE the spray is being applied, one or more observers should be stationed at vantage points in or near each unit being treated. It should be their job to see (1) that weather conditions within the area are satisfactory for spraying and (2) that the pilots are maintaining the proper flight pattern and altitude. When they find that the wind velocity (preferably measured by field anemometers) exceeds the maximum allowable for adequate control, or that the spray is not descending into the trees



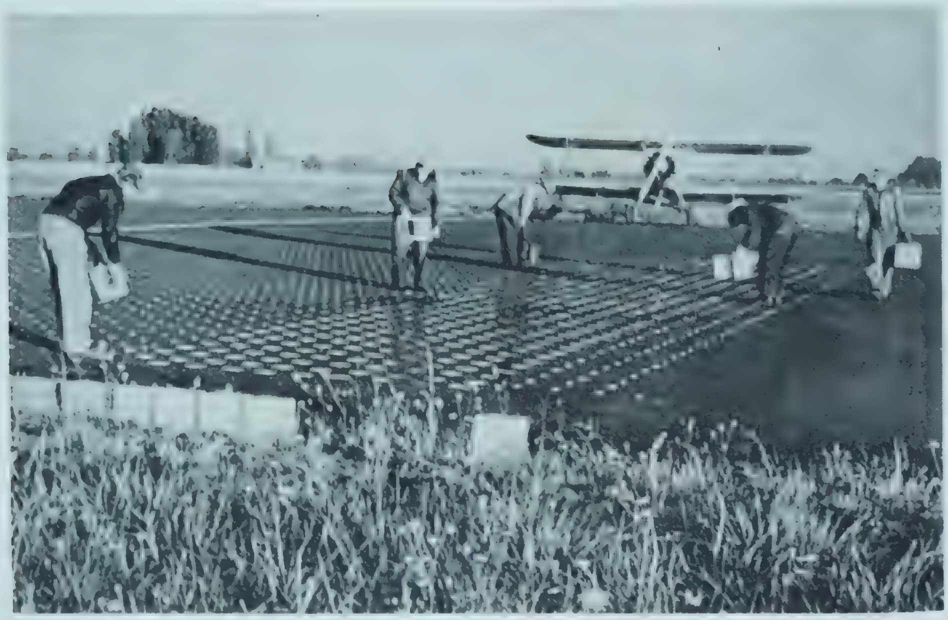


Figure 131. Top: Light boxes for holding and carrying slides.
Bottom: Grid sampling system to determine swath deposit pattern.
From U.S.D.A. Tech. Bull. 1110 by Chamberlin, et al.

properly, they should either inform the man in charge of the operation or signal the pilot to stop spraying.

"If possible, additional observers should be present in each unit to check on the spray coverage. They should place clean glass plates, or dyed papers (each about 4 by 4 inches), preferably in openings, at 50 to 300 foot intervals across the unit, or in as many parts of the unit as possible. They should examine the plates after the morning spraying. If the application has been uniform, they will find that all plates will carry at least a light deposit of small drops. The number of plates to use will vary with the density of the forest canopy. Where solvent-fuel oil solutions are applied, a very thin oily film or sheen will be visible on the foliage. This, too, may be used as an index of coverage, for if most of the leaves on the lower branches and on the understory plants have a visible film or spots of the spray, it is reasonably certain that the upper tree crowns have been adequately treated. The observers should locate all skips or misses in the deposit and spot them on a map for retreatment." (Figures 131, 132.)

Double Swath Widths with Paired Planes

FROM 1952 to 1954, several million acres of forests were sprayed in Canada (Canada Dept. of Agriculture, 1954) using mostly Stearmans equipped with 450 h.p. Pratt & Whitney Wasp Junior engines. In 1952 the rate was one gallon per acre. After 1952, it was decided to extend the insecticide to one-half gallon per acre (Figure 132). Therefore, during calibration, tests were run for swath width in which two aircraft, flying at controlled separation distances, were considered a spraying unit. The emission rate was the same for all aircraft and was that used in 1952 (when, for the first half of the program, aircraft flew singly, and, as the result of tests carried out at that time, employed a theoretical swath width of 100 feet and a theoretical dosage of one gallon per acre). The flow rate was 20.2 gallons per minute.

The results of the tests indicated that in fairly still air, the aircraft could be separated 250 feet with the certainty that their swaths would overlap. They also indicated that the effective swath outside the plane for the purpose of matching consecutive runs was of the order of 75 feet per aircraft. This gave an effective swath width for the double unit of 400 feet and a theoretical dosage of one-half gallon per acre. These tests were backed up by field tests

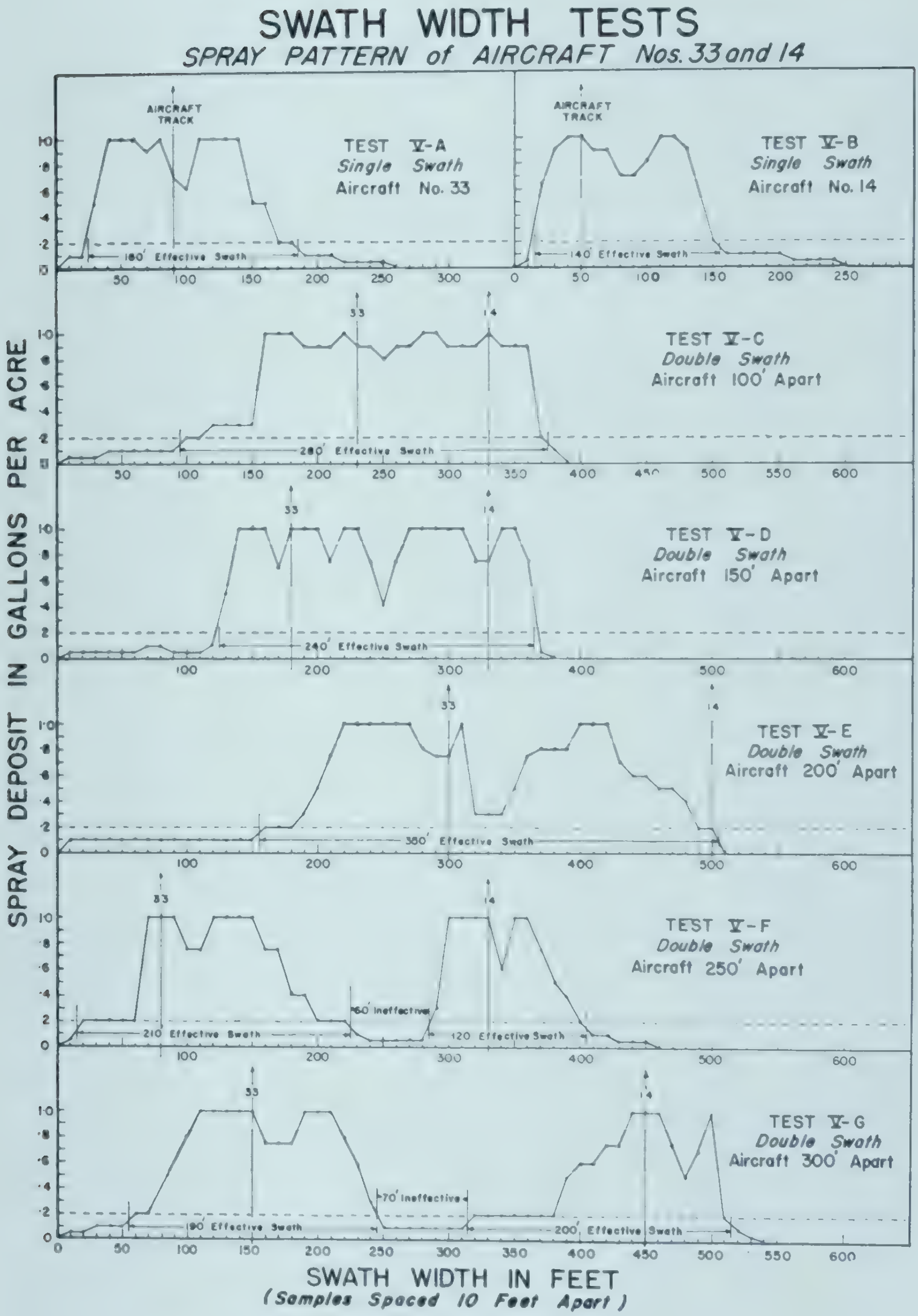


Figure 132. Swath Width Tests.

of an operational nature under ordinary spraying conditions. Indications were that the area missed was very small; in fact, less than had been experienced with single aircraft the year before.

All spraying operations in 1953 were carried out by aircraft flying in pairs, trying to maintain a separation distance between planes of 250 feet. The spraying plan had been developed with this change in technique in mind and much more than the minimum target of 1,000,000 acres had been delineated on maps and photographs. An advantage which seems to stand out in this flying technique beyond that of safety is the rapidity with which forest areas can be covered. This allows the sprayer to buy time when time is very precious, even to the point where a second application can be carried out on the same area in the same season. At one airfield, two applications were given to an area of almost 250,000 acres.

Fifteen mechanics were necessary to keep the fleet of 77 planes flying. Over and above the requirment of the Stearman aircraft (established as a reliable and comparatively safe forest spray plane) and the practice of flying in pairs, which in the event of accident, cuts down the necessity for search, a helicopter stood by at the Chatham R.C.A.F. base during the spraying operations in the event that rescue operations were necessary.

No large forest spraying program could be launched without a reliable communications system. The New Brunswick Forest Service provided Forest Protection Ltd., with an extensive radio hookup, linking together ten fire towers, six airfields, eight observation aircraft, one motor vehicle, and the Forest Protection Ltd. office. The fire towers were occupied by weather observers and a very close tab was kept on the weather at all times.

Large Scale Forest Spraying with Two- and Four-Motored Bombers

USE of the twin-motored C47 type of cargo planes has been discussed. In 1954 an even larger plane (Figure 133) a 4-motored B17 converted bomber capable of carrying up to 3000 gallons of insecticide was used to spray a gypsy moth outbreak in the Lansing, Michigan, area. (O'Dell, 1955.)

In this operation the State Bureau of Plant Industry arranged with the State Police Commissioner for traffic controls during periods of spray application over main thoroughfares entering the

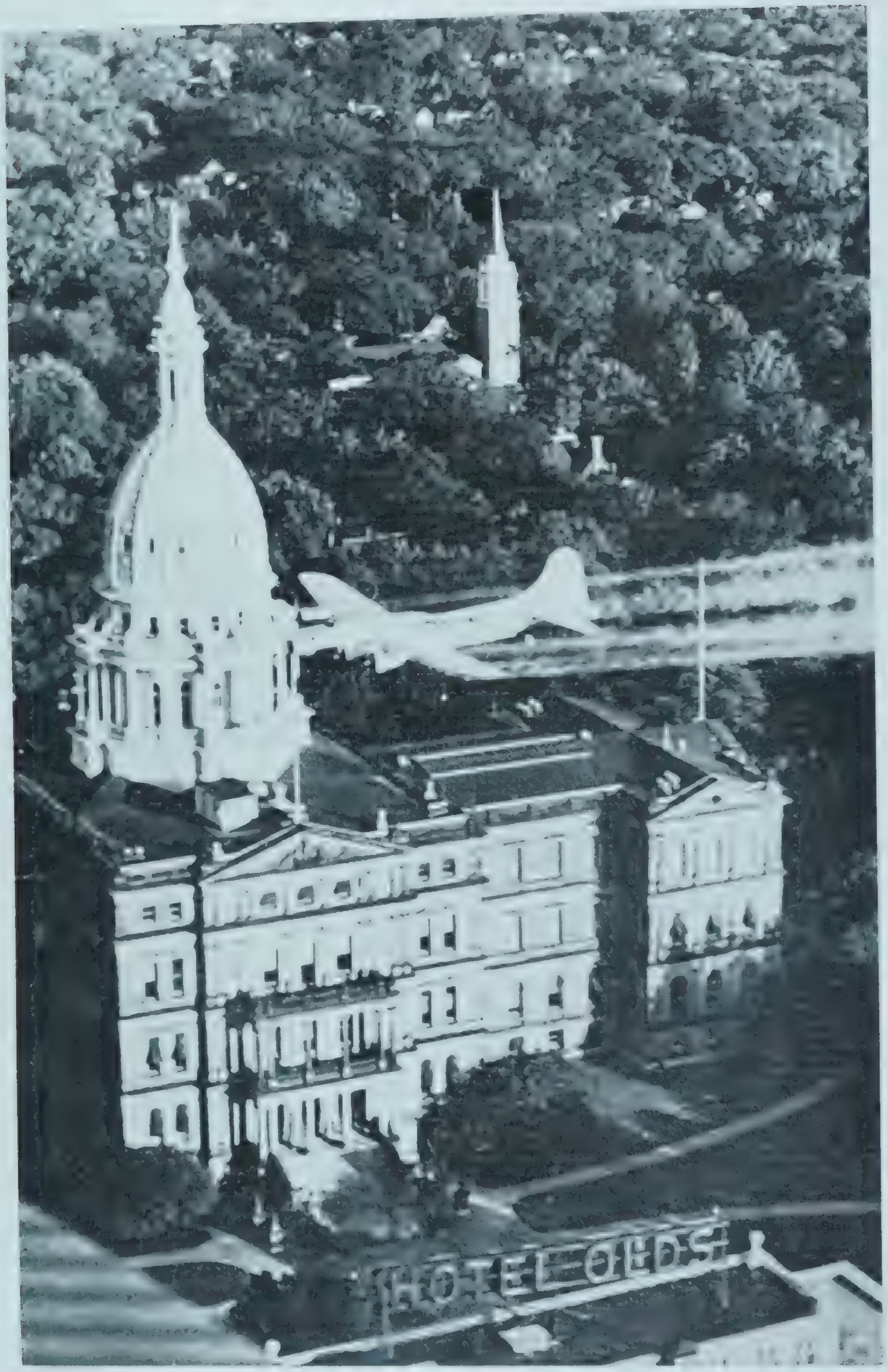


Figure 133. B-17 Airplane spraying for gypsy moth eradication in Lansing, Mich. State Capitol Building is in center foreground.

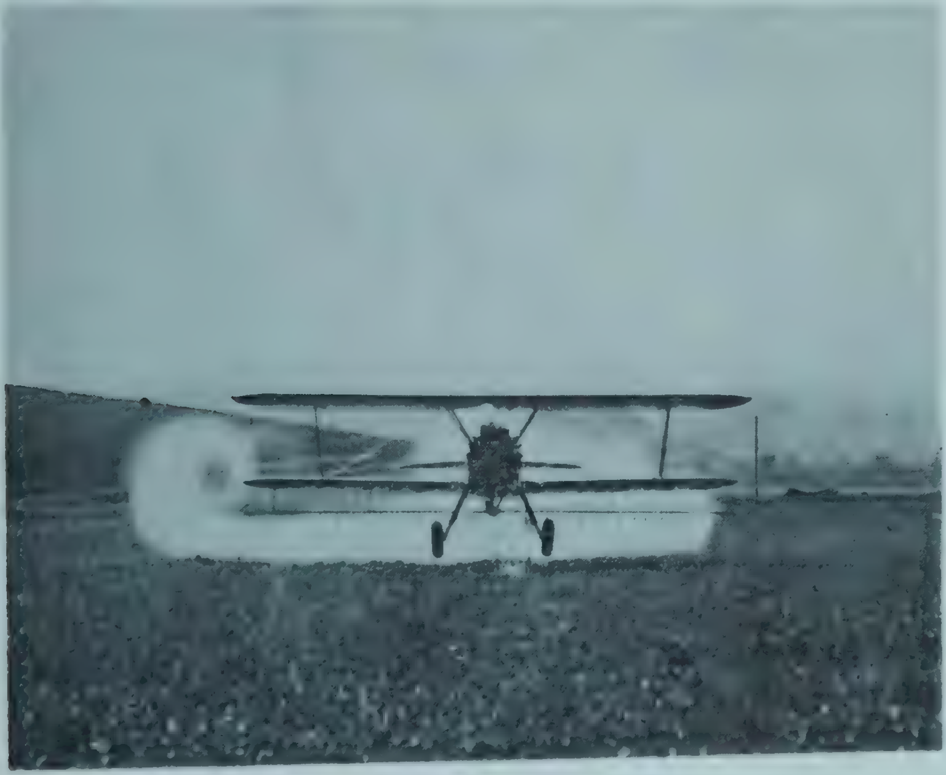
Courtesy, Gypsy Moth Control Project, U.S.D.A., ARS.

cities of Lansing and East Lansing. Similar arrangements were made with the City Police Department in each municipality for slowing traffic during spray operations. Radio broadcasts were made to provide residents with details not covered in daily press releases, and the gypsy moth film in sound and color was projected by television station WKAR at East Lansing.

Insecticide was supplied to the B17 from a 5000 gallon storage tank with a stationary pump. The storage tank was kept supplied by means of a tank-truck shuttle service between the airport and a petroleum plant 3 miles away. The B-17 was equipped with a quick-hitch device under the fuselage to which a 3-inch supply hose could be rapidly connected. The loading time for 2400 gallons averaged 8 to 10 minutes.

Biplanes were loaded directly from oil delivery trucks operated by the petroleum company having the insecticide mixing contract. Because of efficient pumping and metering equipment on these

Figure 134. A Stearman biplane applying spray at low level for control of the pea aphid on canning peas near Walla Walla, Wash., June 9, 1951.



trucks, there was an average elapsed time of only four minutes between the landing and take-off of biplanes at each reloading with 100 gallons of insecticide.

At the conclusion of the program, 59,022 gallons of insecticide had been sprayed on tree and shrub growth within 86,400 acres of territory in five days. The B-17 had applied 40,640 gallons of DDT-oil solution spray and the three Stearman biplanes 18,382 gallons.

An interesting observation is that the large ships like the B-17, flying 500 feet swaths at 150 m.p.h. at the flight level of about 150 feet, give better coverage than cubs and biplanes flying 60 and 120 foot swaths respectively. This may be partly due to swath overlap. However, it is more likely the result of (1) finer atomization that is possible at that speed, and (2) the method of flying. The big ships have a co-pilot who follows the line of flight and markers, using a compass. He may become the pilot on every other swath and the pilot may be the co-pilot on every other swath. The corner flags may be as far as 3 or 4 miles apart, but the "in between" marking and directions are a combination of flares and two-way radio set between ground crew and pilot or co-pilot, plus the observations of the co-pilot. On the ground, two or more men line up in a straight line and set off two or more flares. As the plane approaches the pilot calls out "fire one," "fire two," etc., to line up the pilot.

Sensitized papers or plates are placed on the ground at given intervals, usually before the first swath but sometimes it has to be done just ahead of the pilot as spraying progresses.

Effect of Size and Shape of Area on Deposit

VERY few operators realize the tremendous direct influence of the size and shape of the treatment area on the loss of spray to area outside of it. For example, if we assume that the "outside" area deposit is a 200 foot border around the field to be sprayed, then the area covered outside the treatment area would be 12, 15.8, 23, and 42 acres, respectively for square shaped treatment areas of 5, 10, 25, and 100 areas, respectively. In other words, for plots of 5, 10, 25, and 100 acres the area covered outside of the area to be treated would be respectively, 2.4, 1.58, 0.92, and 0.42 times the area to be treated. These figures are theoretical, of course, but they are not as far off as one might imagine. In actual practice, there are many instances where in spraying areas of 1 to 100 acres 50 to 80 per cent of the deposit was outside of the treatment area. Very narrow, irregular shaped areas are subject to even greater losses.

Loss of deposit is decreased by wide, flat, or square shaped areas, low flying, slow flying, still atmospheric conditions, and experienced pilots.

Application at Low Flight Levels for Crops

IN treating field crops—cotton, vegetables, clover, grain, etc., the spraying characteristics and requirements differ in many respects from those for forest spraying. In crop spraying much of the flying is done 2 to 10 feet above the plants, which reduces spray loss, drift, and swath width. It also permits using smaller droplets since the air turbulence from the moving plane causes a higher proportion of the drops to penetrate the foliage and impinge (deposit) in it.*

In 1947 a well designed series of experiments on low level spraying was begun by Chamberlin, Getzendaner, Hessig, and Young (1955). Their work was with biplanes and high wing monoplanes and in most applications the application rate was 4 gallons per acre. That is about the right gallonage for pea aphid control. The next few pages describe some of their more important work. Some of this material is merely digested from their work and some of it is quoted.

Nozzles Used. The nozzles were of four principal types—(1) the poppet nozzle, a spring-loaded poppet-valve nozzle producing a hollow-cone spray in which the orifice size and discharge rate are governed by pressure (the greater the pressure, the greater the effective opening); (2) the cap nozzle, the hollow-cone nozzle having a turbulence chamber and interchangeable orifice caps (orifice sizes used were Nos. 2, 3, 5, 8, and 10 denoting orifice diameters of 0.078, 0.094, 0.125, 0.156, and 0.187 inch, respectively); (3) the jet nozzle, a diaphram check valve provided with interchangeable cap orifices of various sizes, from which the spray is discharged as a solid stream (orifice sizes as for the cap nozzle); and (4) the disk nozzle, a high-pressure, hollow-cone nozzle containing a whirl plate and an interchangeable orifice disk (No. 6 and 8 orifices, measuring 0.094 and 0.125 inch).

---

* From unpublished notes by S. F. Potts, 1930 to 1936.

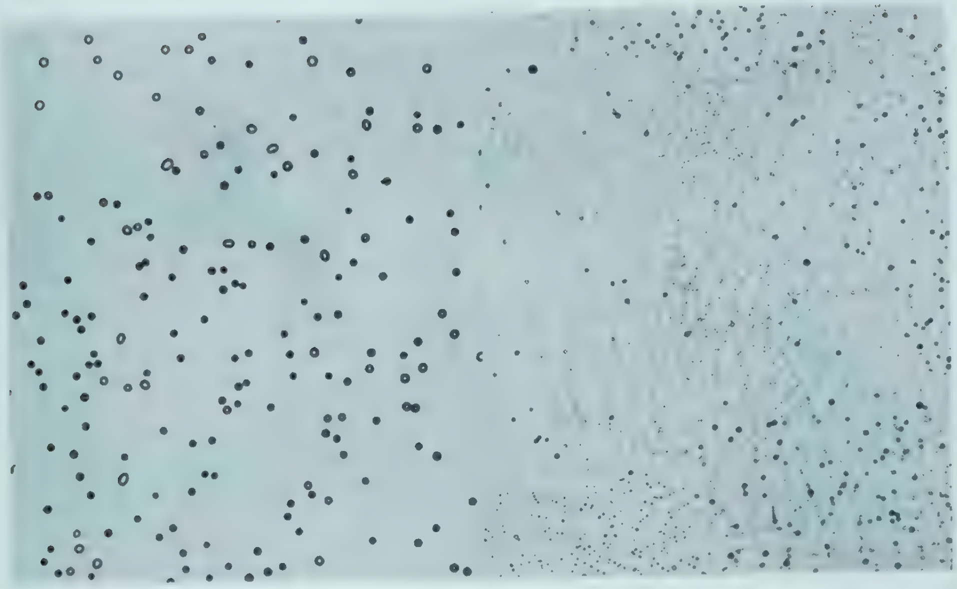


Figure 135. DDT-fuel oil spray deposits of the same dosage (1 pound/1 gallon/acre) applied to Dri-Film coated glass plate

Courtesy C. B. Eaton and J. P. Secrest (USDA)

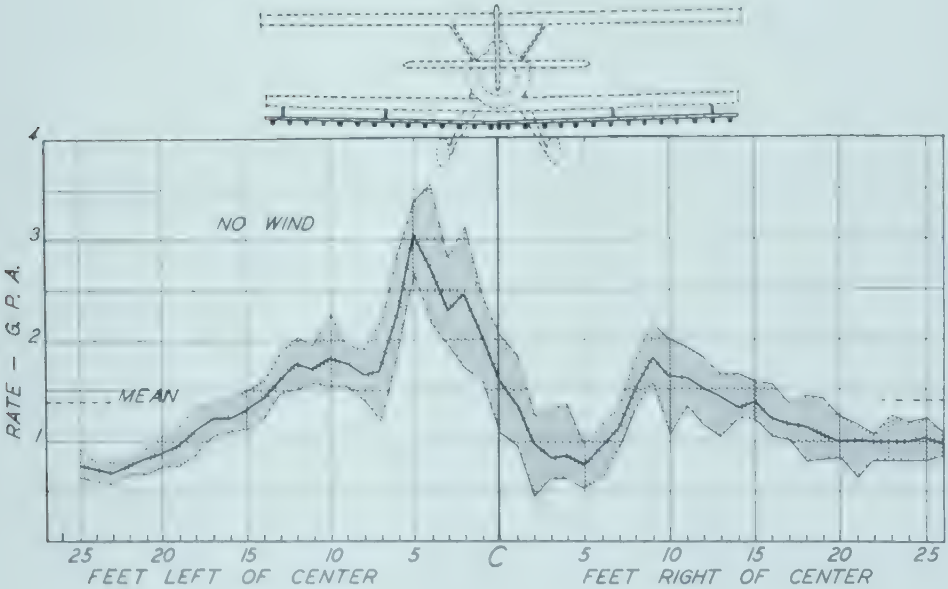


Figure 136. Variation in spray deposit from foot to foot along and across the treated swath in a typical application from uniformly spaced nozzles on a high-lift Stearman biplane flying at a 1-foot level. October 2, 1952.

USDA Bulletin 1110.

The poppet nozzle functions as both a nozzle and a check valve. The cap and jet nozzles were used with individual diaphragm check valves, and the disk nozzle with a ball check valve.

Evolution of Spray Curtain. With aerial equipment operating at 60 to 150 miles per hour, violent air currents are set up which modify the initial symmetry. Figure 134.

These air currents result primarily from the slipstream (vortex) of the rotating propeller and from the vortices generated at either wingtip by the outward flow of air in its spiraling rush to fill the temporary vacuum created by the moving wing. As with the wake produced in water by the passage of a ship, these vortices, plus other effects such as parasite drag components, constitute the elements of an expanding three-dimensional aerial wake in which the spray droplets are suspended until gravitational pull predominates and they settle out. Obviously, the smaller and more buoyant the droplets, the longer they are carried in the wake. The borders of the swath, therefore, are indefinite and merge gradually into the adjacent areas.

"The uniformity of spray deposition within a treated swath cannot be adequately estimated from a sequence of photographs. In this sequence the spray curtain was produced from the uneven nozzle arrangement visible in Figure 134. From an even nozzle arrangement, and at a similar flight level, the development of the spray curtain would appear the same. However, in both cases the actual deposition of spray across the treated swath varies greatly from point to point. This variation in spray deposits from an even arrangement of No. 10 cap nozzles is shown in Figure 136. Determinations were made at 1-foot intervals both across a 50-foot swath and along the swath for eight feet. The maximum, minimum, and mean of the eight deposit values were determined for each distance from the center of the swath. The high peak left of center, the trough right of center*, and subsidiary peaks near either wingtip are typical, although for this particular application the wingtip peaks are not so far outboard as usual.

"In low-level applications the spray curtain is momentarily compressed against the ground. This causes the spray released within the outer wing sections to be squeezed or forced beyond the wing tips into a flat-bottomed spiral. At higher flight levels this ground-cushion effect is not apparent and the wingtip vortices develop normally. Owing to the low angle perspective, these vortices, which

---

* The term "right" or "left" of center refers here to lateral position relative to the direction of the line of flight.

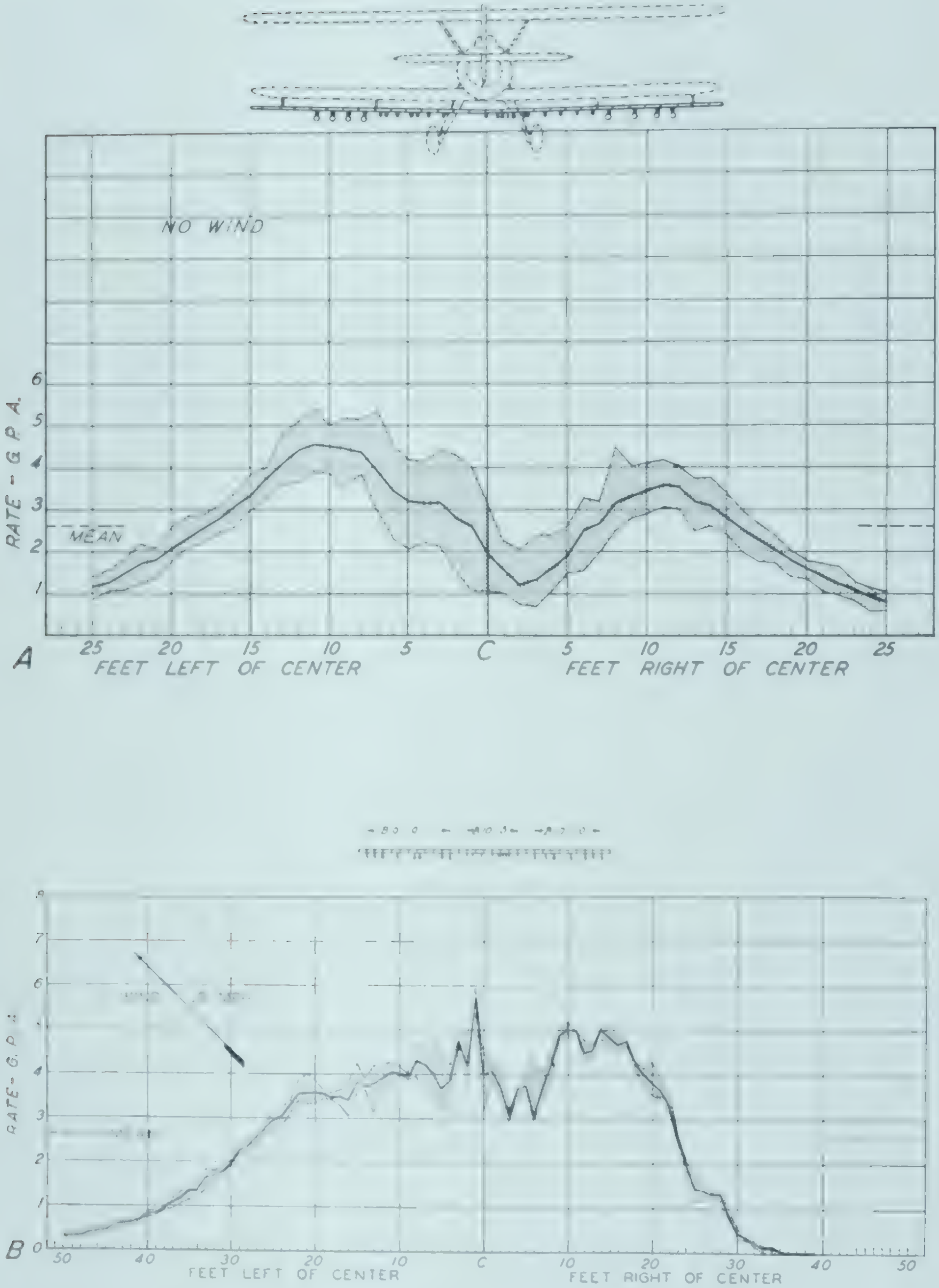


Figure 137. Spray-distribution curves for asymmetrical arrangements of nozzles: **A**, A preliminary arrangement of 8 coarse-spray No. 10 cap nozzles (circles in spacing diagram) outboard and 18 fine-spray No. 3 cap nozzles inboard with application at 2-foot flight level, 1952; **B**, An almost fully compensated arrangement of 15 coarse-spray nozzles outboard and 11 fine-spray nozzles inboard with application at 4-foot level, 1953.

USDA Bulletin 1110.

actually extend further outboard before settling than at lower flight levels, are masked by the descending spray curtain until it has pretty well settled.

Spray discharged from the central boom segments is influenced by the counter-clockwise rotation of the propeller, especially at low-level applications (Figure 134 and 136.) This rotation shifts the spray from right to left, resulting in a high-deposit zone left of center and in a corresponding low-deposit zone right of center. At low flight levels the expanding vortex of the propeller strikes the ground almost immediately, so that the spray is deposited before circulation has been completed and consequently distribution is very erratic. At application levels of 8 to 10 feet, the spray has a greater opportunity to circulate within the propeller slipstream before it is deposited, and hence distribution is more uniform.

Combinations of Fine and Coarse Spray Nozzles. Tests indicated that a better spray pattern should be possible with a combination of coarse-spray nozzles outboard to obtain maximum swath width and fine-spray nozzles inboard for a better mean deposit rate in the right-of-center low.

The fact that fine sprays from low-level applications are deposited more uniformly than coarse sprays, especially in the turbulent wake of the propeller slipstream, also suggested that overall distribution patterns might be substantially improved by combinations of fine-spray nozzles inboard and coarse-spray nozzles outboard.

"Subsequent tests were conducted in which progressive compensatory improvements were made, finally resulting in nozzle combination and spacing which at a 4-foot flight level gave the excellent pattern shown (Figure 137). The right-of-center low was largely eliminated by the judicious spacing of the fine-spray nozzles inboard, while the overall swath width was maintained by the spacing of the coarse nozzles outboard. For this nozzle combination, overall apparent swath widths were found to be 55 feet for vine-top flight levels, 58-60 feet for the 4-foot level, and 65-68 feet for the 10-foot level. These findings were confirmed by experiments conducted in 1953 for control of the pea aphid on canning peas, when effective swaths were 55 feet at vine-top to 4-foot flight levels and 65 feet at the 10-foot level."

The swath pattern was also widened 5 to 8 feet with a modified Stearman equipped with squared wings that affected the wingtip vortices.

Discussion. "From the evidence presented it is clear that spray discharged along the lateral axis of an airplane will follow the air currents set in motion by its passage through the air until these forces will no longer support the weight of the spray droplets.

"Three principal airstreams, from the standpoint of spray distribution, are generated by an airplane in flight—the right and the left wing-tip vortices and the propeller slipstream. They determine the path of the spray discharge and the resultant deposit pattern.

"Three principal spray-boom sections may be recognized:

(1) The center section, comprising that portion of the boom approximately the propeller radius both sides of center and contributing spray to the slipstream.

"(2) The midwing section, comprising that portion of the boom lying outboard of the effects of the propeller slipstream and inboard of the main effects of the wingtip vortex (about 4-7 feet both sides of center with the Stearman biplane). The spray discharged from this section does not contribute significantly to either the wingtip or the propeller vortices, although it is given a distinct outboard impetus by the same forces that produce the former.

"(3) The wingtip section, comprising the outboard portions of the boom (8-15 feet both sides of center with the Stearman biplane) and contributing spray to the wingtip vortices. The bulk of such spray is deposited well beyond the wingtips even at the lowest flight levels.

"Air currents within the propeller slipstream, aside from being driven aft with considerable force, are rotated counterclockwise by the directional effect of the propeller blades. The propeller rotation causes the column of air driven aft to veer off toward the right until overcome by the adjacent airstreams and thence to parallel the direction of flight. The corkscrew effect is strongest immediately aft of the propeller, and the main vortex crosses beneath the fuselage from right to left—up on the left side and back over the fuselage and tail section to the right side. This movement has a tendency to force the wingtip vortex outboard on the right side and to pull in the left vortex toward the center—a phenomenon readily visible to the pilot and in motion picture sequences.

". . . Essentially the same forces obtain for higher flight levels as for low, except that spray-bearing air currents are not so quickly or greatly compressed by contact with the ground.

". . . At low flight levels with a biplane, to minimize the mean peak deposit to the left of center the nozzles should be transferred from the first three feet of boom segment left of center to the first three feet right of center. This tends to build up the low-deposit area to the right of center and somewhat reduce the amount of spray deposited to the left of center. This nozzle arrangement does not prevent erratic extremes of deposit in the wake of the propeller slipstream, but it does give a better mean for this problem area. Similarily, if the maximum effective swath width is to be achieved, more nozzles should be placed in the wingtip than in the midwing zone boom segments, since they necessarily supply a considerably wider section of the overall swath.

". . . With an increase in the height of application there is corresponding decrease in the force with which the propeller slipstream contacts the deposit area. For higher flights the suspended spray can circulate and thus be deposited in a more even and consistent pattern. The spray from applications made above 10 to 15 feet was not markedly distorted by the propeller slipstream. The capacity of the slipstream to support spray depends upon droplet size and specific gravity. A fine spray will remain suspended longer in the slipstream before reaching the deposit area than will a coarse spray.

"Since the distribution of spray within the propeller vortex improves with increased elevation of flight, any other method that would permit the retention of spray droplets within the vortex for a more extended period of the time would also improve the distribution pattern. This can be accomplished for low-level flights by discharging fine to very fine sprays from the center boom sections and coarser sprays outbroad (Figure 137, page 330).

"For applications at 2 to 6 feet, it may be difficult to obtain satisfactory deposit patterns over a maximum effective swath by employing fewer than 20 nozzles. Nevertheless, an excellent pattern has been obtained with as few as 20 nozzles. Satisfactory deposit patterns are dependent upon the nozzle types and spacing, the rate and height of application, the degree of atomization, and last, but not least, pump and line capacity sufficient to supply the outboard nozzles with an adequate amount of spray.

"For low-level applications with a Stearman biplane it appears that a boom of 25 feet or more is required to obtain maximum swath widths. At flight level of 10 to 20 feet satisfactory patterns are obtainable with boom lengths of 20 to 24 feet.

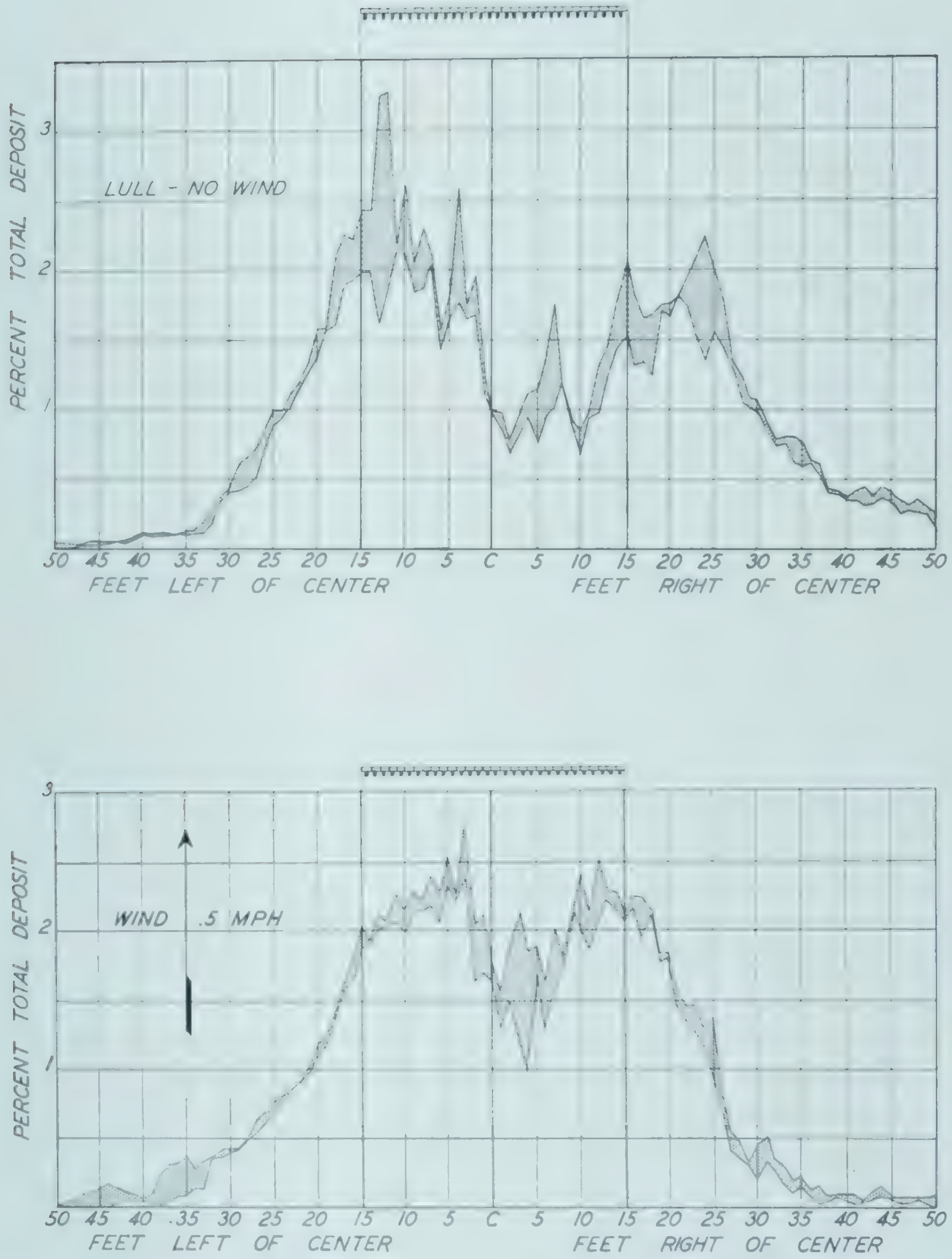


Figure 138. Spray-distribution curves for applications at a 2-foot flight level from 30 evenly spaced nozzles on a Stearman biplane: **A,** Coarse spray from poppet nozzles; **B,** medium spray from No. 8 cap nozzles. 1952.

USDA Bulletin 1110.

"Swath widths vary with the flight level of application. With the Stearman biplane the maximum effective swaths as measured by the control of pea aphids on canning peas were found to be approximately 50-55 feet for 1- to 3-foot, 63-65 feet for 10-foot, and 75-80 feet for 20- to 25-foot flight levels. Optimum flagging intervals are those that allow for an overlap sufficient to maintain a fairly uniform application rate throughout. Improper overlapping increases or accentuates high- and low-deposit zones and may even result in skips. For a low-application level with a single-swath pattern, the optimum flagging interval would be 55 feet. Similarly for a 10-foot flight level the optimum would be 70 feet.

"The problem of applying sprays from aircraft under cross-wind conditions is a complex one. At low-application levels the effect of cross drift is minimized but, unless suitable nozzles and nozzle arrangements are employed, marked streaking may result. Conversely, at application levels of 8 to 10 feet a uniform pattern may be more easily achieved, but the effects of cross winds are much more critical. Such winds pile up the spray on the windward side, often resulting in over application."

Safest Ways to Apply Herbicides by Aircraft

THE following summary by Akesson (1954) outlines suggestions for those concerned with formulating regulations governing applications of 2,4-D in potential or proven sensitive areas.

"A. Equipment of the following design has been found to be the safest and, so far as known, most practical for applying 2,4-D.
   1. Nozzle—cylindrical jet producing type, not less than ⅛ inch diameter, with a simple orifice or tube, and without mechanism causing a sheet, cone, fan or other dispersion.
   2. Nozzle discharge should be directed with slipstream or a maximum of 10 degrees downward from the horizontal for reducing chances of spray hitting fuselage and tail surfaces.
   3. Pressure measured at nozzle not over 45 p.s.i.
   4. No nozzles to be placed within three feet of each wing tip on fixed-wing plane, to reduce amount of spray drawn into wing tip vortices.
   5. Positive liquid shut-off system, using one of following:
      (a) Individual nozzle check valves, plus suckback device.
      (b) Individual nozzle check valves, plus boom pressure release device.
      (c) Individual nozzle positive action valves.

"B. Horizontal air movements: Many theoretical expressions for the possible relation of this factor to damage need proving in the field. However, safety must be emphasized until such can be accomplished.

1. Air motion not to exceed 5 m.p.h. measured by acceptable anemometer, five feet or more above the ground at the treated field.
2. Continuous, measurable wind movement from one direction away from local susceptible crops with a suggested minimum of 1 m.p.h. A minimum distance to a susceptible crop downwind might be indicated and should be five miles or more, depending on the crop and the local area.
3. Field under question should not be sprayed if susceptible commercial crop is within one-half mile in any direction from the treatment.
4. No turns should be permitted over any susceptible crop during treatment, take-offs, or landings. A minimum altitude while ferrying over susceptible crops might be specified.

"C. Vertical air motion or diffusion: Knowledge is limited as to the actual manner in which 2,4-D is diffused, but a maximum temperature is not as important as the temperature gradient, which usually follows a daily predictable pattern in a given area.

1. When the temperature measured within 10 feet of the ground at the treatment area exceeds 80 degrees F., spraying should not be continued more than six hours after sunrise and commenced not earlier than ½ hour after sunset.
2. When temperature is less than 80 degrees F., spraying can be conducted as long as other limitations (nozzles, wind velocity, etc.) do not apply.

"D. Quantity of 2,4-D applied within a given area: This is probably workable only under extreme conditions when a "hazardous area" designation is impending.

1. When it is found a given area is prone to damage and other methods fail to achieve protection, means might be taken to reduce the total amount of 2,4-D applied (a) during one day to the entire area, or (b) during the entire season to the entire area, or (c) to any given field either by day or season. When susceptible crops are located in the natural air drainage path of a treated area, the amount of 2,4-D released should

be carefully watched and no 2,4-D should be applied when this normal air motion pattern is under way.

"Because of the changing picture as regards the formulation and use of 2,4-D, it is desirable to keep the regulations affecting its use flexible and readily subject to alteration when and if it is found desirable to do so."

Pilot Training, Employment, and Safety

THE selection, training, and protection of pilots is a very important problem. The average pilot's salary is now about 7000 dollars a year. In the United States there are some 7000 pilots in this business, some 2500 to 3000 of whom are probably poorly qualified. Pilots coming out of military service and commercial aviation are trained in taking off and landing on big, established airports and in flying high and fast. Those conditions are quite different from laying down parallel swaths in low flight over an irregular-shaped 40-acre field or woodland at 65 to 90 miles per hour with an over-loaded plane and, often with snags, trees and power lines at the ends of the area.

There are three critical problems associated with the words "Aerial Applicator Pilot."

1. New sources of aerial applicator pilots.
2. The need for specialized training facilities and proficiency training for both new and experienced pilots.
3. The use of proper protective equipment by pilots to prevent injury in case of accidents.

The information that follows on pilot training and safety was extracted from a paper by Hanson (1955).

An experienced operator knows that it takes about four years to make a good applicator of a pilot. He has an equipment investment of $4,000 to $10,000 per airplane. His customers are becoming fussier each year about doing a better job. If that isn't enough, the operator still has the insurance company to deal with. So the operator should be suspicious right away of the self-glamorizing tales many of the applicants tell about themselves and decide that they probably won't do. Often after much searching for suitable pilots, one finally comes along who really looks good and won't mind being a flunkie for a season to learn the business. A substantial investment in training carries him through the critical stages to the point where he looks pretty good. Then very likely your competitor, who has had none of the grief and expense of the pilot's training process, comes along and offers him perhaps 30 per cent more than you can afford to pay and you lose your pilot. So, actually the operator as contractor needs some protection. And by the same token the pilot needs some income and protection during the training period. A partial solution can be in the formation of operator-pilot-associations to interchange pilots among members, compile duster-pilot ratings and to perform other business of mutual benefit to members.

But what of the number one critical problem—New Sources of Aerial Applicator Pilots?

The best answer to this problem is that a few land grant colleges

Detailed Listing by Operational Phase
of a Study of 178 Agricultural Aviation Accidents, 1954
(Condensed from Hanson, 1955)

Operational Phase	*No. of Crashes*
1. Loading	1
2. Starting	3
3. Taxi for takeoff	0
4. Takeoff	14
5. Climb-out from takeoff	23
6. Enroute to treat crops	4
7. Survey of field	1
8. Starting swath run	4
9. During swath run	21
10. Pull-up from swath run	28
11. Procedure turnaround	18
12. Flare out for swath run	24
13. Cleanup swath	6
14. Maneuvering to avoid obstructions	5
15. Return to strip	7
16. Landing phase	23
17. Taxi after landing	0
18. Parking	0
19. Testing airplane	0
20. Testing-calibrating equipment	0
21. Training pilots	3
22. Ferry phase	3
23. Other	1

and two or three federal research centers with equipment, flying fields, and personnel should conduct appropriate pilot and operator training courses, covering all phases of agricultural aviation. This is extremely urgent.

The next important problem is that of *accident prevention*. A study of the first 178 agricultural aviation accidents of 1954 is given on the facing page in 23 distinct operational phases.

Summary of Accident Study

OUT of the 178 accidents, green pilots accounted for 86 and experienced pilots 92. Over half of the pilots were listed as "experienced."

Nearly half of the green pilots' accidents, but less than one-fourth of the experienced pilots' accidents, were fatal or caused serious injury. This gives the experienced pilots a 2 to 1 survival rate over green pilots in accidents.

Green pilots had 16 overloaded and 18 underloaded fatal or serious injury accidents, while experienced pilots had only 19 underloaded ones. Here we find over twice as many fatal or serious injury accidents resulting from underloaded conditions.

There were 166 washout accidents and major damage accidents. Over two-thirds of these accidents occurred when the airplane was underloaded, while less than one-third occurred when overloaded conditions existed. Green pilots had slightly more than half of these.

Thirty-seven accidents, or over 21 per cent resulted from lack of runway length or space available for takeoff and climbout. Green pilots accounted for 16 of these and experienced pilots 21.

Some surprise is justified at the number of accidents which experienced pilots have in planes that are underloaded. A good pilot is especially careful when he starts out with a heavy load, careful in his turns and all maneuvers. As his load lightens, he demands more performance from his airplane. That is where he runs into an accident. It proves that even experienced pilots need more training in handling their planes when they are lightly loaded. Certainly the inexperienced pilot needs such training.

These figures have other meaning, also: that pilots and those whose fields are being treated must be taught that it isn't necessary to drag your wheels six inches below the crops to get the job done; that pilots must be taught to make swath runs at the plane's cruising speed, instead of in a nose high, near stall attitude—an attitude which keeps the airplane flying at its maximum angle of attack, leaving no safety margin to clear obstructions.

Pilots should be taught not to be overconfident as the airplane lightens; and must understand airplane performance under takeoff and climbout conditions—for aerial spraying is not very forgiving of first mistakes.

There is one more critical problem that needs an answer. It is the use of protective equipment by pilots to prevent injury in case of an accident, including use or non-use of shoulder harness, crash helmets, and protection against poisonous chemicals.

Summary of Use of Protective Equipment

ONE hundred and ten pilots wore shoulder harness, 68 did not. Of the 32 fatalities in these accidents, 18 did not wear shoulder harness, while 14 did. That is a 2 to 1 survival rate in favor of shoulder harness.

The advantage of crash helmets becomes very obvious as the report is studied. Out of the 178 accidents only nine pilots wore crash helmets. Crash helmets were not used by any of the 32 fatalities and 25 received fatal head injuries. Crash helmets were not used by the 22 pilots suffering major injuries and 11 of them received major head injuries.

There were nine accidents definitely attributed to chemical effect or poisoning of the pilot. Four (2.3 per cent) were fatal, two were major injury, and three were minor. One pilot used good protective equipment, but it was dislodged by the accident. Three pilots used, but discarded, the protective equipment, and four pilots did not use it at all.

Here again facts speak for themselves. They indicate that use of shoulder harness, crash helmets, and proper protective equipment for the application of poisonous chemicals is certainly indicated.

An outstanding fact is that, with the exception of one or two thermal aerosol accidents, practically no fires resulted from the use in aircraft of so-called flammable solvents and carriers like benzene, xylene, toluene, acetone, and kerosene. These studies covered a period of 10 years. Over two million acres have been treated using benzene as the solvent where all the other components of the mixture (excepting the insecticide) are classed as flammable.

Aerial Applicators' Responsibilities Toward Safety and Good Insect Control

GAINES (1955) points out that "it is essential for the aerial applicator to make a legitimate profit in order to furnish the planter with good applications of chemicals which are necessary to good insect control. These charges can only be made in a business where a good accounting system is kept. Many factors such as depreciation, taxes, salaries, insurance, general operation expenses, etc. are involved in estimating costs.

"Good pilots with a moral responsibility are essential. The welfare of the aerial applicator's business is in the hands of the pilot. He is the one that should fly the correct width swaths, apply the chemicals evenly, clean up the ends properly and be careful not to allow drifts to create hazards to livestock or pollinators. It is essential that a job be well done in order to create more business and indirectly bring in higher income for the company.

Precautions. "Many of the phosphorous insecticides are dangerous and care should be exercised in their use. It is true some of them will control certain insect pests much better than any other group of compounds. Some of the phosphorous compounds act systemically, that is, the plant will translocate the chemical in the sap stream to other parts of the plant, thus controlling insects during a long period of time.

"Parathion, TEPP and demeton may injure humans by inhalation or by absorption through the skin so special precautions should be taken in dealing with them in contrast to the commonly used chlorinated hydrocarbons.

"The following suggested precautions are listed:

1. Special care should be exercised to prevent flagmen from coming in contact with the spray.

2. Flagmen should not walk through the sprayed plants and all field men should remain out of treated fields during the day of treatment.

3. Each forester, planter, or customer should be fully advised before treatment is made and thoroughly warned as to the hazards involved.

4. Gloves, goggles and respirators with suitable filters and cartridges should be worn by all personnel handling the concentrate or spray.

5. Cigarettes should not be carried in clothing while around these chemicals and personnel should wash and clean-up before smoking or eating.

6. Pilots should not stay in the plane during the loading operation.

7. Pilot should avoid flying back in his own swath.

8. In case of a leak, where spray or fumes may get in the cockpit, the pilot should land immediately and correct it.

9. Pilots should take special care to prevent sprays from getting into occupied houses or on food crops. Where crops are growing in close proximity to either houses or gardens, the spray should be cut off far enough in advance to insure safety. These areas may be covered with ground machinery or with a less toxic chemical by planes.

10. Ships and spray equipment should be thoroughly washed after using the materials and care should be exercised to prevent the waste from endangering humans or livestock.

11. During mixing operations, care should be exercised in handling the materials, in order to prevent spilling them on one's clothing or person, and no one should be allowed to come in close proximity to the mixer.

12. All empty containers should be destroyed so as not to become a hazard.

13. Control the flow of liquid in the hose with the valve at the mixer to prevent accidental nozzle leaks or hose splitting."

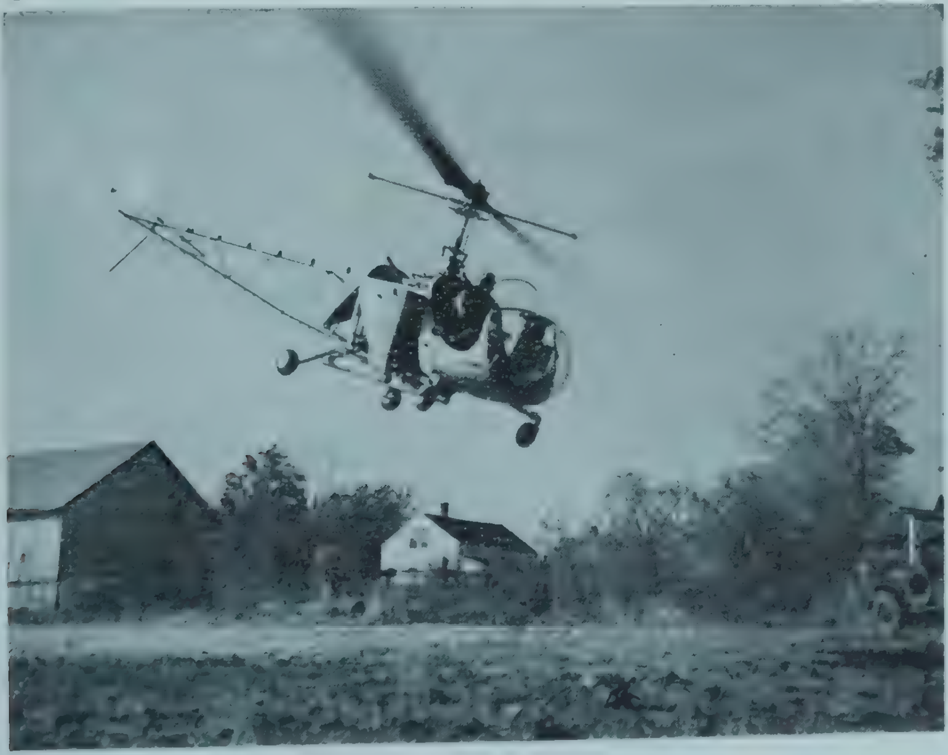
Helicopter Application

BY combining many of the features of the mist blower and the airplane the helicopter becomes the most interesting and versatile aerial applicator. However, it is not yet the ideal aerial spray machine because of its high initial cost, present restricted load-carrying capacity and special pilot training requirement. Helicopters, new types of airplanes, convertaplanes and jet-rotor aircraft are gradually setting the stage for the development of more suitable aircraft applicators.

In spite of its handicaps, the helicopter possesses the following three distinct features that should enable it to effect good control of such insect pests and plant diseases as require a high degree of coverage: (1) The swirling downward air blast from the rotors of one to two million cubic feet of air per minute at 15 to 25 miles per hour, when hovering, (2) the ability to maneuver, hover, and fly slowly, and (3) a potential supply of air for atomizing the spray mixture without a spray boom. Heretofore, an important potential advantage of the helicopter has been wasted by using the boom (Figure 139). Usually the average numerical drop diameter from the boom has ranged from roughly 200 to 320 microns for helicopter application as compared to 125 to 180 microns for airplane application. Hence the airplane has delivered a finer spray than the boom-equipped helicopter due to the slower air speed of the latter.

The most serious fault of helicopter application has been too coarse atomization of the spray. The airplane effects considerable spray breakup by flying at speeds of over 50 m.p.h. but the helicopter must be capable of providing fine atomization at essentially no flight speed. The optimum drop diameter for mist blowers is about 40 microns. For helicopters the optimum diameter for most conditions is between 40 and 60 microns. An exception is the treatment of forests under conditions which require the aircraft to fly high and fast,—as 40 to 60 feet high at speeds of 40 m.p.h. or greater.

Figure 139 Showing helicopter landing in backyard after spraying street elms with boom equipped with No. 1 whirljet nozzles pointing upwards against the rotor's downdraft.



PARTIAL LIST OF MANUFACTURERS OF AIRPLANE SPRAYING EQUIPMENT, 1955

Arrow Sprayer Manufacturing Co.
Clinton Airport
Box 188
Clinton, Illinois

Burnum Aviation Company, Inc.
Arlington, Texas

Callair
Box 246
Afton, Wyoming

Central Aircraft Inc.
Yakima, Washington

Clark Aircraft, Inc.
Marshall, Texas

Dakota Aviation Company
Distributor for Sevdy-Sorensen Sprayers
Box 18
Huron, South Dakota

Hawthorne Aircraft Industries
Valley View Ranch
Lucerne Valley, California

Tom Herrod
PO Box 45
Geraldine, Montana

I-C-D Equipment Company
Box 355
Campbell, California

Larson Aero Development
Concord, California

Lehava Air Services
1802 South Taylor Street
Philadelphia, Pa.

Marsh Aviation, Inc.
2407 Airline Way
Phoenix, Arizona

Mississippi Valley Aircraft Service
Fletcher Field
P. O. Box 522
Clarksdale, Mississippi

Ong Aircraft Corporation
Ong Airport
P. O. Box 214
Kansas City, Missouri

Oda Spray Equipment Company
Box 383
Buffalo, Oklahoma

Pickell and Associates
5707 York Blvd.
Los Angeles, California

Piper Aircraft Corp.
Lock Haven, Conn.

Harold L. Root
PO Box 642
Exeter, California

Simpson & Whitney Aviation
Liberal, Kansas

Skyparts
259 Panama
Chico, California

Transland Company
2610 West 247th St.
Torrance, California

Art Whitaker
P. O. Box 1811
Portland 11, Oregon

The primary reasons for constructing the air blast apparatus described below were the need for: (1) *much* finer atomization at 0 to 60 m.p.h. air speed, (2) the use of large orifices and fewer nozzles to permit application of suspensions, (3) mechanical agitation while the helicopter is standing on the ground as well as when it is in flight, (4) an instantaneous spray shut-off device to eliminate spray drippage, and (5) to reduce its weight. (Potts and Spencer, 1953).

Load Distribution. A big problem in helicopter spraying is balance. The simplest way to solve it is to install two tanks, one on each side of the fuselage directly under the rotor, and as close to the center of gravity as possible. The outfit should be planned so that the spray is pumped simultaneously from both tanks.

Air Blast Assembly. Because of the limitations imposed by weight, horse power, and type of pump required, a combination of air blast and 40 pounds nozzle pressure was the most promising means at our disposal for atomizing the spray. A primary objective, therefore, was to determine the optimum air velocity and volume to produce given average drop sizes at given spray delivery rates. The studies were facilitated by ground tests with mist blowers followed by tests of the apparatus on the helicopter.

The apparatus is described by Potts and Spencer (1953) as follows:

"Two 25 gallon tanks, one on each side of the helicopter hold the spray mixture. The assembly utilizes the air blast of the cooling fan of the helicopter engine to atomize the mixture delivered at 40 p.s.i. from a centrifugal pump through various types of nozzles, including whirljet Nos. 1, 2, 3, 5 and 10.* At the fan, the air is delivered into two, five-inch diameter ducts each of which terminates in a four inch diameter outlet with spray nozzles 1½ inches beyond the mouth of the outlet. The nozzles are attached to a ring with their orifices ¼ inch outside of the air blast and pointed at right angles to the direction of the air stream (Figure 140). The mouths of the two outlets are 7 to 8 feet apart and the overall length of each duct is 6 to 7 feet. The two outlets are pointed towards the rear of the machine at an angle of about 10 degrees from the line on flight (Figure 141). Increasing this angle and increasing the length of the ducts increases the swath width. However, if this angle is

---

*Numbers 1, 2, 3, 5, and 10 have orifices of 1/16, 5/64, 3/32, 1/8, and 3/32 inch, respectively.

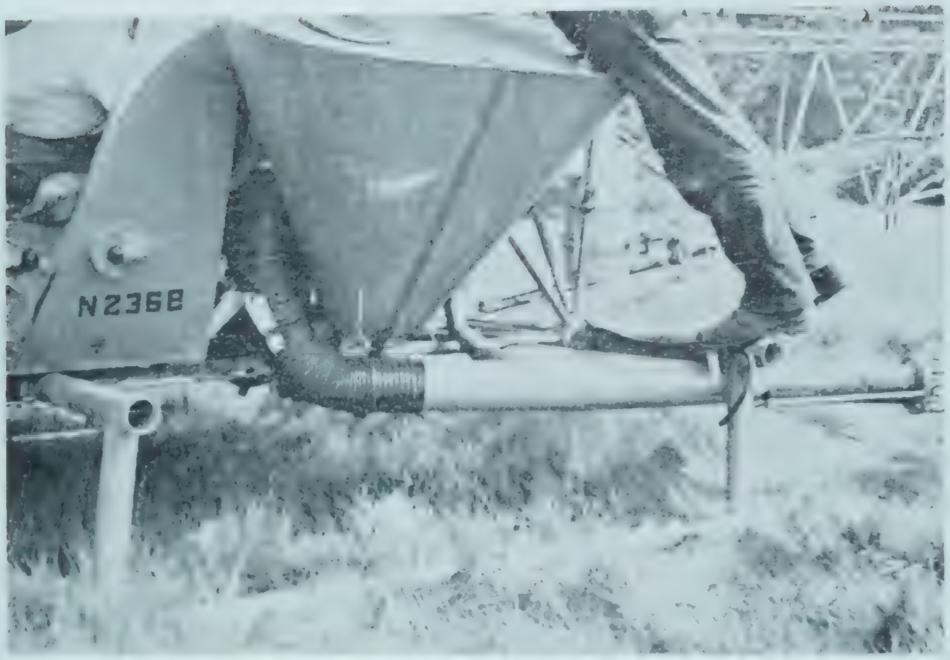


Figure 140. Spray tank and air outlet of one side. Outlet leads from the cooling fan to a nozzle manifold of four, No. 5 whirljet nozzles pointing at right angles to the air stream. The helicopter is fitted with skids to permit landing on marshes. Ring at outlet may be fitted with $\frac{1}{8}$ inch connections for a maximum of 24 nozzles (each side). Agitator is installed at bottom of tank

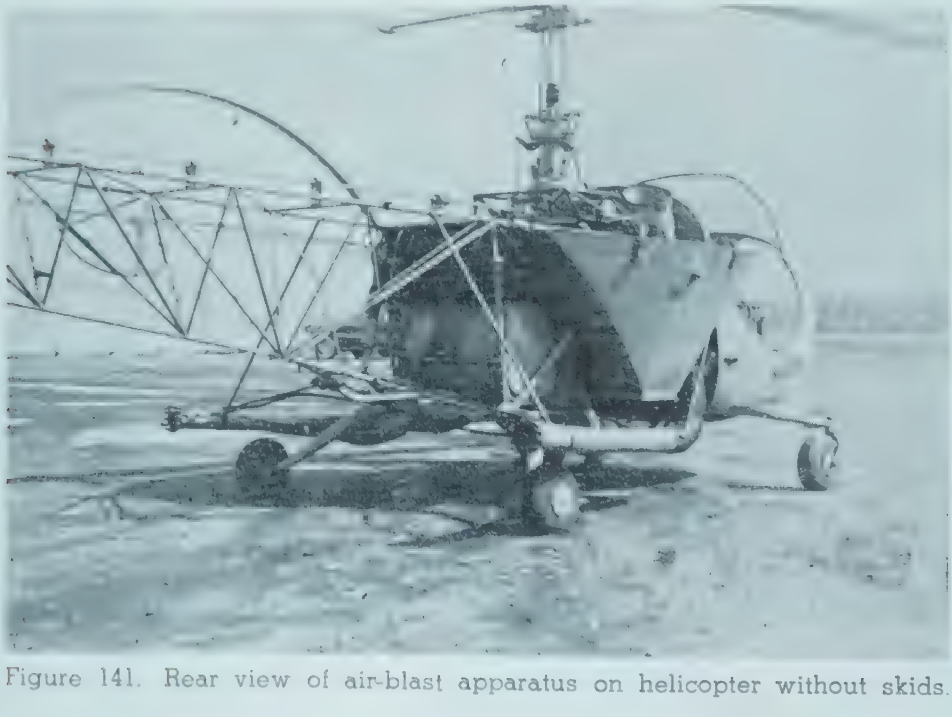


Figure 141. Rear view of air-blast apparatus on helicopter without skids.

much greater than 20 degrees there is often a narrow strip of weak deposit in the center of the swath. The bend in the air ducts leading from the fan must be as gradual and as short as possible since abrupt bends and long pipes reduce air velocity. Air from the cooling fan passes through the outlets at the rate of 85-90 miles per hour. This velocity is enough when using No. 1 and No. 2 whirljet nozzles, but is not quite enough for sufficient atomization with larger nozzle orifices at low pressure (40 p.s.i.), as when applying suspensions. Mass average drop diameters of approximately 50 and 65 microns are obtained when using No. 1 and No. 2 whirljet nozzles, respectively.

To Apply Suspensions. "To obtain the higher velocity needed for nozzles with large orifices (as whirljet Nos. 5, 10, etc.) the two exhaust stacks of the helicopter engine are removed, inverted, and each attached to a two-foot length of flexible two inch diameter stainless steel tubing that empties into each of the two metal ends of the air ducts 12 to 16 inches back of the air outlet (Figure 140 and 141). This makes an overall length of 40 inches for the two inch exhaust ducts. To avoid losing air velocity the exhaust air and cooling fan air must be moving in the same line of travel where the two streams merge. This arrangement increases the air velocity to 120 m.p.h. The hot air, which moves at 175 m.p.h from the exhaust, is cooled to a temperature of 90°F. by the larger volume of air from the cooling fan, plus the large volume of spray from the nozzles. A mass average drop diameter of about 45 microns with a range of 10 to 110 microns results when using No. 5 whirljet nozzles. The whole apparatus is about 25 pounds lighter than was the boom attachment."

CAUTION: Do not land in or allow the helicopter to remain in a field of dead or dry grass that is high enough to touch the hot exhaust gas pipes.

The spray shut-off is instantaneous, which eliminates drool.

"Since mechanical agitation of the spray mixture is needed for the application of suspensions, a propeller type agitator with 6 blades is installed in each of the two, 25-gallon insecticide tanks. These two agitators are driven by two, 0.25 h.p. electric motors which in turn are driven by a storage battery. This arrangement provides agitation while the aircraft is standing on the ground as well as when it is in flight."

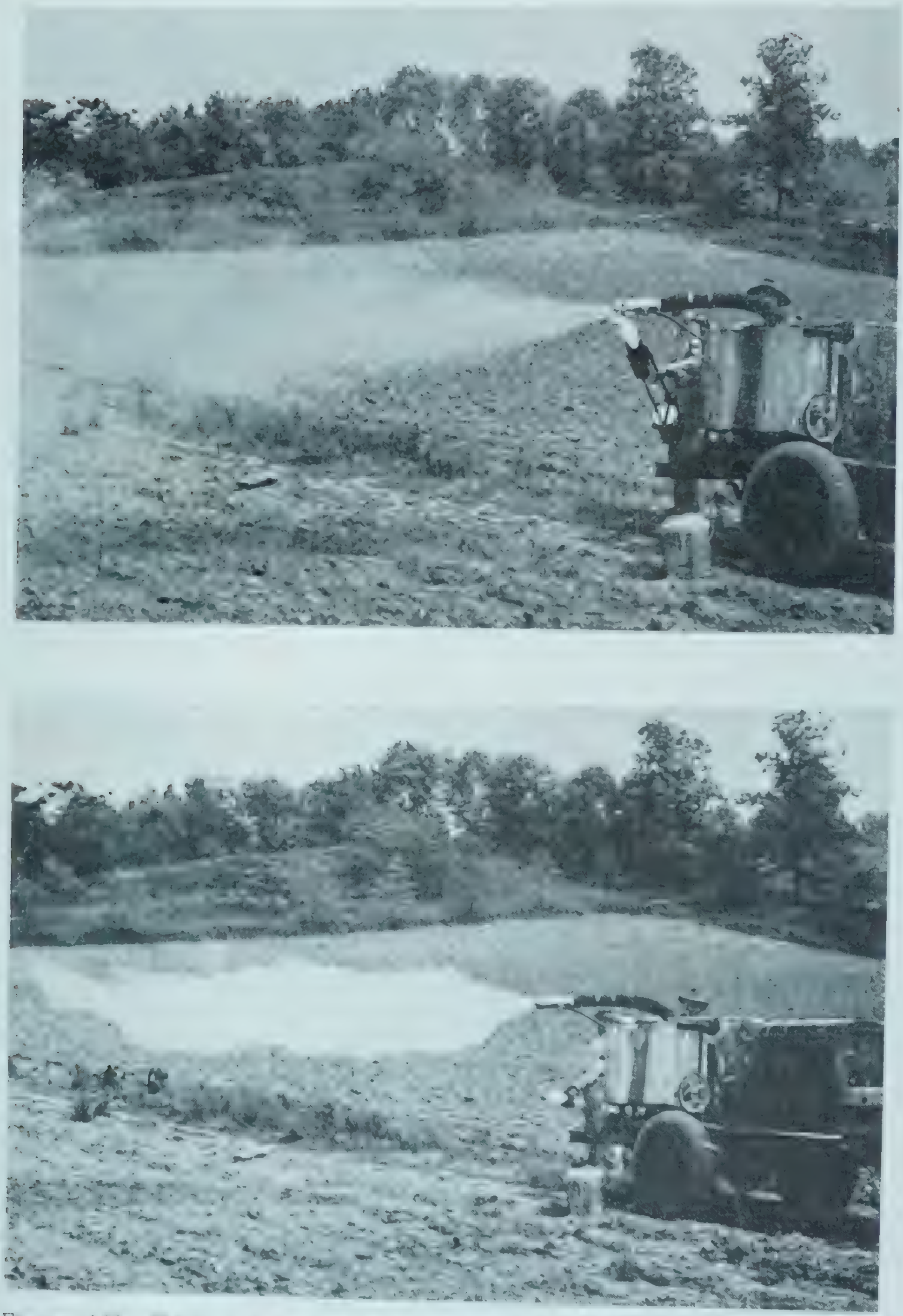


Figure 142. Flash tests using mist blower weed blow torch and various flammable chemicals. **Top:** Type of torch lighted flame from atomized straight benzene, xylene and kerosene. After lighting the flame it can be instantly turned off with the spray shut-off valve. **Bottom:** A slight trace of flashing in a 50% kerosene-water emulsion which disappeared with removal of the torch. Carbon sparks did not produce flashing.

Application of Spray-coated Dusts. "A device has been improvised for simultaneously applying dust and spray to coat as much of the dust with spray liquid as feasible. The arrangement consists of feeding dust from a hopper into the air stream of the air ducts. As this dust passes through the discharge pipe it mixes with the spray at the mouth of the outlet where the ring of spray nozzles is located. Trials were made on the ground with 40 percent oil emulsion spray liquid delivered at 2, 4, 8 and 12 g.p.m. respectively, while the dust was discharged at 20, 40, 80, 120 pounds per minute. At these rates it is estimated that about half of the dust was well coated. A higher proportion of dust can be wetted if it is pre-mixed with 5 to 12 per cent of its weight of oil, glycerine, or other non-volatile liquid before being poured into the hopper. While the application of "spray-dust" or "wet-dust" may not have as wide use as spray alone, in some cases spray-dust is preferable to spray alone, as when two or more pesticides are not stable or compatible in the same mixture."

Limitations in the Use of Exhaust Gases. A careful study has been made of the possibilities of the exhaust air constituting a fire hazard when applying inflammable liquids like xylene, kerosene, etc. Severe flash tests were made using flames and carbon sparks. (Figure 142). The atomized air-spray steam from xylene and kerosene solution could be ignited by a weed blow torch that threw a flame four inches in diameter and 3 to 4 feet long. The ignited air blast flame never came closer than six inches to the outlet or the machine. The flame always vanished as soon as the spray was shut off. The straight kerosene-xylene solution gave 2 or 3 flashes in actual helicopter spray operations. No flashes resulted when the mixture contained 50 per cent or more of water as in all emulsion and suspension sprays; and no flashes resulted if the straight oils had a-viscosity exceeding 44 seconds Saybolt. For such mixtures the use of the exhaust is perfectly safe. For the inflammable kerosene xylene solution the exhaust must be disconnected and the spray atomized by air from the cooling fan alone. In this case small orifice nozzles such as whirljets B1 and B2 can be used, as there should be no clogging problem with solutions or soluble emulsions.

Suggested Adaptations in Helicopter Construction. Helicopters used for spraying should be provided with a fan, or fans, that will provide sufficient air velocity and volume to handle any type mixture without the exhaust. An ideal apparatus should deliver air at 135 m.p.h. through three properly placed, five inch diameter outlets. The center outlet could point forward or aft of the aircraft, with the other two outlets pointed to the rear of the machine at an angle of about 15 degrees from the line of flight. Such an arrangement would deliver a much wider swath than anything yet developed, and the apparatus would be capable of finely atomizing up to 25 gallons of mixture.

Tests with the Apparatus. Most of one season's efforts were directed toward testing the new apparatus for deposit, distribution, swath width, and drop size in a comparison of (a) boom equipment, (b) air blast equipment without the exhaust gases, and (c) air blast apparatus with the increased air velocity caused by introducing the engine's exhaust gases into the outlet.

The mixture applied was a 10 per cent DDT emulsion containing per gallon: one quart of Velsicol AR 60, 1½ ounces of emulsifier, and the requisite quantity of water. It was applied at 35 pounds pressure. The temperature ranged from 36°F. to 45°F. and the humidity ranged from 70% to 80%. The pilot was asked to fly 15 feet above ground at a speed of 20 miles per hour. Accurate stop watch records for each run showed that the aircraft averaged almost consistently a speed of 30 m.p.h. The 15-foot flight height level was maintained in each case.

The No. 5 whirljet nozzles were used in all tests made with the airblast combination of cooling fan air plus exhaust gases. No. 2 whirljets were used in tests with both the boom and with the cooling fan air-blast alone. (Table 58)

Table 58. Basic Application Data For Comparative Equipment Tests.

No. Test	Type of Atomizing spray apparatus	Size of whirljet nozzles	Spray delivery in gals/min.	Pounds of DDT delivered per 210 linear[a] Feet of Swath	Per Cent of DDT recovered
1	Cooling fan plus exhaust	No. 5	7.32	0.6148	60
2	Cooling fan plus exhaust	No. 5	14.60	1.22	64
3	Cooling fan alone	No. 2	7.32	0.6148	70
4	Boom of 24 whirl jet nozzles	No. 2	8.40	0.801	60.5

a/ 209 x 209 ft. = 1 acre

The drop size and coverage data are summarized in table 59 below. Test No. 2 was made primarily to determine the effect on drop size of doubling the spray delivery rate.

From 1936 to 1938 the author made studies of deposit re-

Table 59. Drop size and coverage with various types of equipment listed in preceding table.

Test No.	Spray Apparatus	Spray delivered in gals/min.	Numerical average drop diameter (microns)	Mass average drop diameter (microns)	Number of drops per square millimeter	Number of drops per square inch
1	Air blast plus exhaust, No. 5 nozzles	7.32	55.	63	36	2322
2	Air blast plus exhaust, No. 5 nozzles	14.6	63.3	73	5.6*	3612*
3	Air blast from cooling fan alone	7.32	74.4	85	2.3	1483
4	Boom apparatus with No. 2 whirljets	8.4	163.3	195	0.15	97

Twice as much gallonage was applied in test No. 2 as in test No. 1. If the figures in test No. 2 are divided by two, there would be 2.8 drops per square millimeter or 1806 drops per square inch, respectively.

Table 60. Swath and deposit distribution data from equipment listed in the two preceding tables[a]

			Per cent of deposit in			Per cent of deposit		
Test No.	Flight No.	Over-all width of swath (feet)	Heaviest 25 feet of swath	Second heaviest 25 feet of swath	Third heaviest 25 feet of swath	In heaviest 25 feet of swath	In heaviest 50 feet of swath	In heaviest 75 feet of swath
1	1	265	36.	19.3	24.	36	55.6	79.5
	2	270						
3	3	250	46.8	24.5	17.7	46.8	71.35	89.
	4	260						
4	5	145	46.7	31.2	13.5	46.7	78	92
	6	160						

[a] In tests 1, 3, and 4 respectively, 20.5, 11, and 8 per cent of the deposit was outside of the heaviest 75 feet of swath.

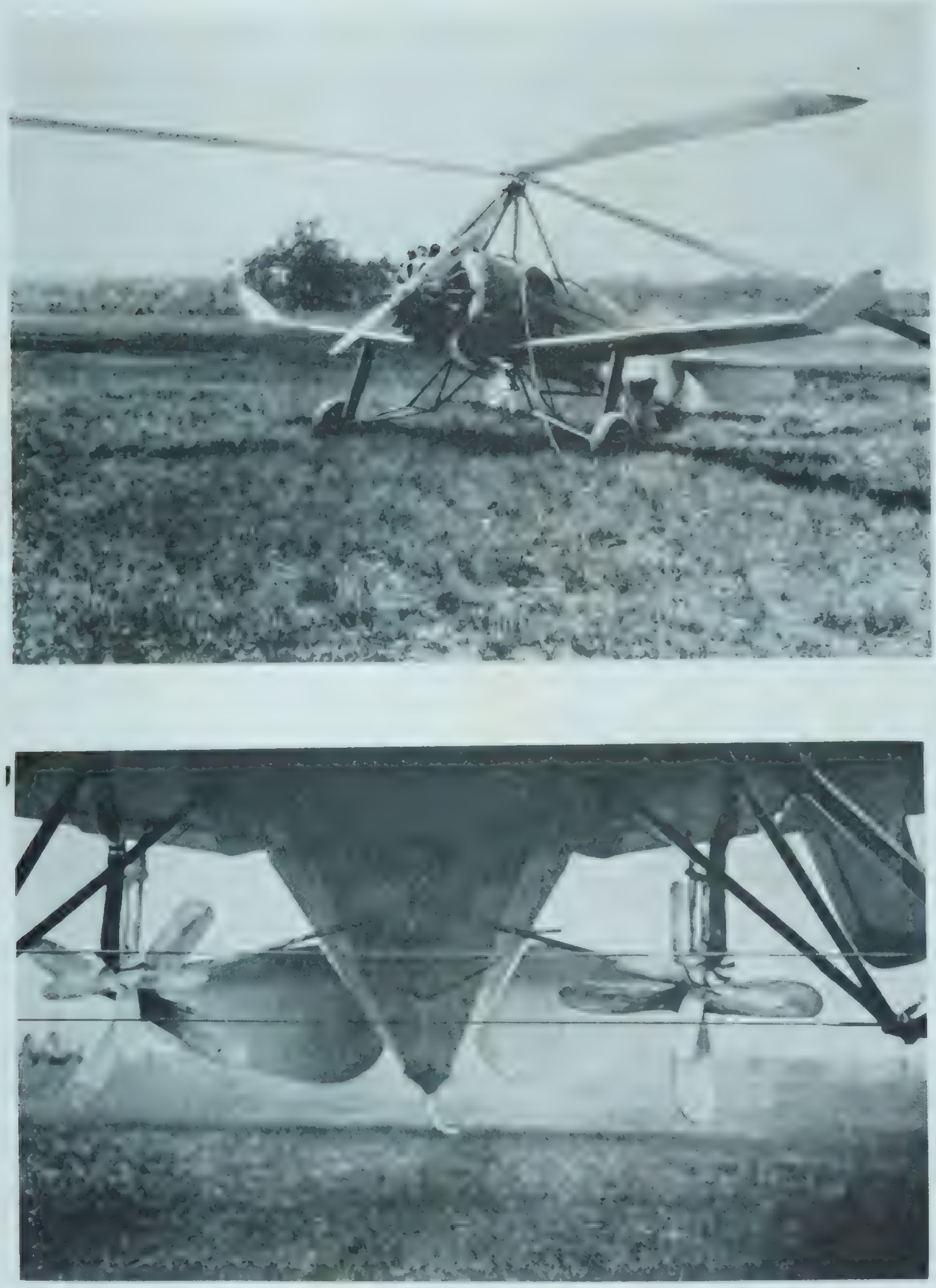


Figure 143. The old autogiro, a relic of the past, equipped with one of numerous devices designed for it to distribute spray concentrates.

From the author's notes, 1935.

coveries distributed through the canopy and on the ground for sprays delivered by autogiros (Figure 143). In a 100-acre woodland of .6 to .7 canopy density a lead arsenate concentrate was applied at the rate of 5 gallons per acre. A recovery of 64 per cent of the insecticide applied was obtained. Thirty-six per cent of this recovery was on the ground and 64 per cent of it was on the foliage. On the foliage, the deposit was distributed over the equivalent of five layers of foliage, since the area of foliage was five times (5 acres per acre) the ground area, so that an average of only 12.8 per cent of the deposit recovered was on each layer of foliage. The relative deposit per square inch in the top one-third, middle one-third, and bottom one-third of the canopy was 17, 11.6, and 9.7, respectively, as compared to 36 for the ground. A well-stocked stand of conifers has 50 to 80 per cent more foliage area than a well stocked deciduous stand so that the deposit per unit area of foliage is somewhat less for the conifers. Also, the ground deposit is considerably less under conifers due to the denser overstory.

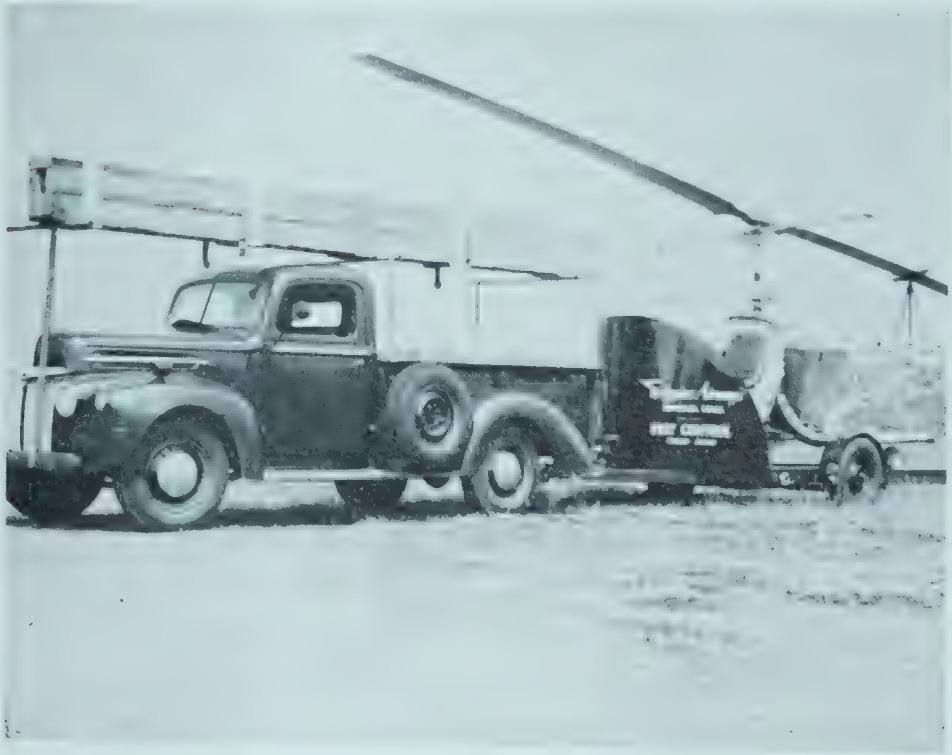
Applications. Except for load and capacity limitations the helicopter is capable of making any applications that airplanes make and many others besides. The air blast spraying device described above has been used successfully on various pests, including the elm bark beetle, elm leaf beetle, nursery pests, cankerworms, gypsy moth, white pine weevil, mosquitoes, and pests of cranberry bogs and orchards. The apparatus is well suited in principle for treating small or irregular shaped areas, truck crops, orchards, and shade grown tobacco. Shade tobacco and individual shade trees, for example, require fine atomization and precision treatment. Shade tobacco leaves are very tender and may be seriously damaged by coarse drops, heavy oil carriers, and non volatile aromatic solvents. On the other hand, finely atomized mixtures of wettable powders or finely atomized emulsions containing volatile solvents like xylene, are relatively safe. Also, up to 75 per cent of fine spray (averaging 40 microns in diameter) went through the 16 inch mesh netting, whereas, when the droplets averaged 175 microns in diameter, only 30 per cent of the spray went through the netting.

When treating elms for the elm bark beetles to control Dutch elm diseases the helicopter must preferably hover over the tree or at least move slowly (5 to 15 m.p.h.) over it so as to drive air from the rotors through the tree crown. Two or three passes are required for a large elm.

In addition to aerial application of insecticides for pest control, aeroplanes and helicopters have increased their scope of operations in the industry to include sowing of seeds, fertilizing with both dry and liquid materials, and the application of herbicides to small grains for weed problems. Defoliating plants prior to harvest is another job done by plane. Chemical crop drying is in the experimental stage on crops like maize to reduce moisture in the field. What of the future? —it is inevitable that greater use will be made of aerial application, as farmers become acquainted with and experience the many services of this relatively new aid to farming.

Helicopter Trailer. In cooperation with Wiggins Airways of Norwood, Mass., a trailer was developed for transporting the helicopter along highways to reduce ferrying costs. Figure 144) When transporting the machine the two top rotor blades are usually removed and the helicopter with apparatus attached is drawn by a trailer truck or by an auto.

Figure 144. Trailer frame for transporting helicopter over roads



Applications with Booms and Other Devices. In the absence of the air-blast apparatus a medium-fine solution or emulsion spray can be delivered from oil burner nozzle tips at 40 to 200 p.s.i. Since the nozzles may deliver only 5 to 10 g.p.h. per nozzle it will be necessary to use 75 to 200 nozzle tips. They may be placed in clusters along a boom or on some suitable undercarriage fixture of the aircraft.

The ordinary boom is also suited for treatments that work best with coarser sprays as for the control of brush and deciduous trees in woodlands and along power lines, a purpose for which the helicopter is a very useful tool.

Power line right of-ways may vary from 30 feet to 200 feet in width and the power line may run down the middle of the right-of-way strip at a height of 40 feet or more above it. In general, it is too dangerous for the pilot to fly directly over the line. Therefore, he must be able to fly to one or both sides of the line and throw the spray under the line as well as to both sides of it to effect over-all coverage. For best results this necessitates low, slow flying, relatively coarse atomization to avoid drift and a distributing device for throwing the spray from one side of the machine to a considerable distance in the direction of the power line. The single, high-output 5 to 20 g.p.m. boomless nozzle described for weed control in chapter III is best suited for this purpose. The next best substitute is the hollow tube nozzle system previously described in this chapter. The No. 5 and No. 10 whirljet nozzles at fairly low pressure may be used with fair success, with the nozzles pointing downward along a boom. Arrangement should be made for shutting off the nozzles that are on the side away from the power line.

In the application of silvicides like 2,4,5-T the helicopter has already demonstrated its ability to release coniferous seedlings and trees that are growing in competition with hardwood sprouts, brush, and overstory. This portends to be a highly useful field of application.

Work Suggested in Agricultural Aviation

Any set of suggestions for future work should include:

1. The development and manufacture of suitable airplanes, helicopters, and convertaplanes designed for agricultural use.
2. Studies of means of using air velocity to atomize sprays to any degree of fineness desired.
3. Methods of reducing loss of spray to upper air currents without increasing drop size, especially at high flight levels.

4. Installation of suitable, light-weight metering devices in the cockpit.
5. Methods of gearing spray output directly with the speed of the aircraft.
6. Mechanical agitation. Some insecticides, most fungicides, and many heavy fertilizer mixtures require more agitation, especially when the loaded plane is on the ground, than is supplied by small centrifugal pumps.
7. Marking and coverage. Better marking methods and more efficient means of following parallel swaths are needed, together with a quick, simple method by which the pilot can readily read from the air acreage of a field to be treated, the quantity of spray delivered, quantity of spray remaining in the tank, and acreage covered.
8. Studies of the degree of impingement, deposit, and undercoverage by small droplets at low flight levels.
9. Development of methods for producing given uniform drop sizes for herbicide application to reduce the drift hazard.
10. Coverage, relative toxicity and effectiveness: This important broad field needs thorough, extensive investigation for all of the more promising insecticides, fungicides, nutrients, fertilizers, systemics, hormones, herbicides, and combination mixtures. The materials should be tested at a range of dosages and concentrations. They also should be tested in given drop sizes; and in given volumes per acre, such as ½, 1, 2, 3, 4, 5, 7.5, 10, gallons per acre, etc. Studies should include effects of the chemicals on the various crops and trees as well as on pests.
11. A thorough study should be made of the rate of spray loss and drift as affected by atomization, temperature, humidity and volatilization of volatile ingredients in the mixtures, such as water, benzene, alcohol, xylene, kerosene, etc. Chemicals and methods for reducing these losses should be investigated.
12. Education and instruction. The first need is for instructors and research workers in the agricultural colleges and experiment stations to become thoroughly versed in aerial application and the problems it raises. This is not merely a prerequisite for research and developmental work. It is necessary for the teaching of students, instructors in teachers colleges and junior colleges, county agents, and other agricultural workers. Other groups who are badly in need of instruction include potential

users, pilots, operators, and the press. Unfortunately, the press has received precious little of the facts; whereas numerous misguided wild life groups, amateurs, fanatics, and headline seekers have been very vocal and harmful.

13. Pesticide application laws. Some degree of uniformity of state laws should prevail in the 48 states with only such variations as are needed to cover local conditions. A study of state laws suggests that a good over-all state law can be developed or formulated from several of the better state laws, such as that for Texas, Arizona, California, North Carolina, Nebraska, Ohio, and Iowa. Perhaps the U.S. Departments of Agriculture and Commerce could help in the formulation of such laws.

Wild Life

ARE fish and wildlife harmed by insecticides? DDT application at the rate of a pound or less an acre has produced no serious effect on birds or mammals. This dosage can, under certain conditions, cause injury to aquatic life. Game fish are little affected by applications of 1 pound per acre, but the forms providing the bulk of fish food are sometimes sharply depleted. High dosages, on the other hand, can be very injurious. Therefore, with DDT, or other new insecticides, the application rate should be held to the minimum required for effective control of the insect and, particularly where extensive areas are to be treated, the work should be done under expert guidance.

Literature Cited

Agricultural Aviation Research Conference—2nd. 1954 and 1955 reports. Sponsored by Agricultural Research Service. U.S. Dept. Agriculture. 83 pp.

Akesson, N. B. 1954. Drift problem in the application of 2,4-D by aircraft. 2nd Agricultural Aviation Research Conference, U.S. Dept., Agr., A.R.S., p. 32.

Anonymous. 1948. Aircraft for spraying and dusting. U.S. Dept. Agriculture, Bur. Ent. and Plant Quar., A.R.A., EC-2.

Anonymous. 1954. How to spray the aircraft way. U.S. Dept. Agriculture, Farmers Bul. No. 2062. 30 pp.

Bailey, S. F. and L. M. Smith. 1951. Handbook of Agricultural Pest Control. Industry Publications, 191 pp., illus.

Brown, A.W.A. 1951. Insect Control by Chemicals (Chapter 6). John Wiley & Sons, Inc. New York

Canada Dept. of Agriculture. 1954. Spruce budworm spraying project in New Brunswick. Science Service, Forest Biology Div., Vol. 10. Report No. 5.

Chamberlin, J. C., C. W. Getzendaner, H. H. Hessig, and V. D. Young. 1955. Studies of airplane spray-deposit patterns at low-flight levels. U.S. Dept. Agriculture, Tech. Bul. 1110, 45 pp., illus.

Faulkner, F. S. and C. C. Deonier. 1948. Equipment for dispersing insecticides from aircraft. U.S. Dept. Agriculture. Bur. Ent. and Plant Quar., ET-262, illus.

Faulkner, F. S., C. C. Deonier, and A. N. Davis. 1950. Gravity flow equipment for dispersing insecticides from aircraft. U.S. Dept. Agriculture, Bur. Ent. and Plant Quar., ET-284, processed.

Gaines, J. C. 1955. Principles of insect control. 4th Annual Texas Agricultural Aviation Conference, pp. A3-A4.

Geuting, J. T., Jr. 1954. Problems incident to the development and marketing of agricultural aircraft. Report of Agricultural Aviation Research Conference (Chicago, Ill.) pp. 9-11.

Hanson, G. F. 1955. Aerial applicator pilot. 4th Annual Texas Agricultural Conference, pp. 1-13.

Hawes, Ina L. and R. Eisenberg. 1947. Bibliography of aviation and economic entomology. U.S. Dept. Agriculture, Bibliog. Bul. 8, 186 pp.

Hedden, O. K. 1952. Aerial-spray equipment for a Piper Cub J-3 airplane. U. S. Dept. Agriculture, Bur. Plant Ind., Soils, and Agr. Eng. Information series No 88, illus.

Husman, C. N., O. M. Longcoy, and H. S. Hensley. 1946. Equipment for the dispersal of DDT insecticides by means of aircraft. U.S. Dept. Agriculture, Bur. Ent. and Plant Quar., ET-228, processed, 17 pp., illus.

Isler, D. A. 1948. Aerial spray equipment for Stearman N2S airplane. U.S. Dept. Agriculture. Bur. Plant Ind., Soils and Agr. Eng. Information series No. 87.

O'Dell, W. V. 1955. The gypsy moth outbreak in Michigan. *Jour. Econ. Ent.* 48(2) : 170-172.

Potts, S. F. 1929. Spraying woodlands with an autogiro for control of the gypsy moth. *Jour. Econ. Ent.* 32(3) : 381-386.

———————, 1940. Concentrated spray mixtures and their application by ground and aerial equipment. U.S. Dept. Agriculture, Bur. Ent. and Plant Quar., E-508, 22 pp., illus.

———————, 1946. Particle size and its relation to application, distribution, and deposit. *Jour. Econ. Ent.* 39(6) : 716-722.

———————, and R. A. Spencer. 1953. Air-blast spraying apparatus for helicopters. *Jour. Econ. Ent.* 46(1) : 148-150

Texas Agricultural Aviation Conference, sponsored by Texas A & M College, Texas Aeronautical Commission, and Texas Flying Farmers Association. (1952 to 1955).

Weick, F. E. 1954. Aircraft spraying and dusting. *Agricultural and Food Chemistry* 2(11) : 546.

Yuill, J. S., C. B. Eaton, and D. A. Isler. 1951. Airplane spraying for forest pest control. U.S. Dept. Agriculture, Bur. Ent. and Plant Quar., E-823, 21 pp.

CHAPTER V

MIXTURES

CHAPTER V contains information on methods of mixing and formulating insecticides and fungicides for ground and aerial application; calibration charts for mixtures; insecticide-fungicide compatibility charts; methods of converting federal and state spray schedules and other recommendations for concentrate application; dosage and gallonage for given X-concentrations; adjuncts for use in mixtures to improve efficiency; and other worth while information on spray materials.

Essential information on mixtures includes the requisites of application; methods of preparation; dosage; concentration; dilution; gallonage; combination sprays; formulations for specific pests; wetting, spreading, and adhesive compounds, and sources of supply for the chemicals and equipment. Reference should also be made to Chapters III and IV for information on equipment and methods for applying the materials. The optimum volume to use per unit area will vary with the application method, and the pest, kind of toxicant, and the inclusion or exclusion of suitable spreaders, stickers, and hydroscopic chemicals.

Manufacturers of pesticides are concerned with such items as labeling; shipping laws; recommendations; weight and shipping cost of actual pesticide per pound of total material; fire hazards, container weight, leakage, breakage problems, rust and corrosion; preseason analysis of consumer demands; promotion potentialities; and information for formulators.

Formulators, processors, and middle men have some of the problems of the manufacturer. However, they are confronted mostly with mixing methods and facilities and mixture combinations as well as ready-to-use packages of suitable sizes to meet local needs in their particular territory. They must have enough, but not too much, stock on hand for any occasion and should be familiar with all federal and state experiment station recommendations and qualify as sort of extension pesticide experts.

If you are a *potential* user you should know such things as the kind and nature of your pest problems, whether treatment is justified; what application apparatus and method is most appropriate; what dealers carry the materials you may need; should ready-to-use materials be purchased or should chemicals be bought separately and then mixed; how much material is needed; how should it be measured, mixed, and applied; the simplest way to arrive at the proper dosage, concentration and volume; and which materials are best from the standpoint of pesticide tolerance, safety and effectiveness, as well as special notices regarding exact timing of necessary applications.

Other things being equal, solutions and emulsions are always preferred over wettable powder suspensions because of nozzle clogging and agitation requirements and other problems.

Selection of Pesticide & Mixture

THE main items to consider in selecting a pesticide mixture are its cost; effectiveness; concentration of the toxicant; stability; compatibility; degree of safety for plants, livestock, wild life, and people; adhesiveness and length of residual effectiveness; ease of handling and availability; and effect on application equipment and containers. There are so many different materials that the trained scientist is often at a loss to name the "best" one for a given purpose.

Cost—Prices may be misleading. One material may sell for three dollars per gallon and another may sell for 10 dollars. However, if the first preparation must be diluted at one part per 100 parts of water, 100 gallons of spray will cost three dollars. If the second preparation is effective at one part to 800 parts of water, it will cost but $1.25 per 100 gallons of diluted spray. Furthermore, it often pays to figure the cost of ingredients of dual and triple purpose preparations containing a number of insecticides, fungicides, and nutrients and to purchase and add them separately to the diluted spray. The size of the area and requirements per unit area will govern the amount of material to procure.

Labeling—It is misleading if insecticide packages are labeled in such a way as to imply that wetting agents, emulsifying agents, penetrants, solvents, and other ingredients are part of the total toxicants. A preparation containing 5 per cent nicotine, soap (actual dry basis) 20 per cent, pine oil 10 per cent, alcohol 15 per cent, and water 50 per cent, might be labeled:

INGREDIENTS	%	INERT INGREDIENTS	%
Nicotine (principal toxicant)	5	alcohol	15
Soap (dry weight)	20	water	50
Pine oil	10		

The needs of the user will be best served if any insecticide offered for sale bears a label stating:

1. The name, brand, and trade marks of the product.
2. The name and address of the manufacturer.
3. The chemical analysis, giving the percentages of substances having insecticidal or fungicidal properties, and the percentage of inert ingredients.
4. The net weight and volume of the contents of the package and the weight per gallon.
5. A poison label and an antidote statement if it contains ingredients harmful to human beings.
6. Adequate directions on how to mix, dilute and apply for given pests as
    - (a) Dilute sprays and dusts
    - (b) Concentrated sprays, including,
        - (a) low gallonage equipment
        - (b) Mist blowers
        - (c) Aircraft

The directions should be such as to enable even the small home owner to make up as little as a pint, quart, or gallon of spray.

The hazard of accidental poisoning of persons in handling packaged pesticides is not great, but some hazard does exist. The danger is greatest with small quantities put up for household and home garden use. Sodium fluoride roach powder, poisonous ant baits, parathion, and TEPP present the greatest danger, with dry powdered arsenicals next on the list.

Proper packaging will do much to remove hazards. Poisonous powdered household insecticides should be sold in substantial cardboard, fibre, or metal containers, preferably so constructed as to prevent ready removal of large amounts of the powder. They should never be sold in flimsy paper bags or light cardboard cartons that break readily.

Additional information on labeling may be obtained from an article by H. C. Fuller (1940). The most recent information on labeling and food tolerances can also be obtained through the National Agricultural Chemicals Association, 1145 19th St., N.W., Washington 6, D. C. A guide for the preparation of warning labels for hazardous chemicals, including economic poisons, has been prepared by the Manufacturing Chemists Association, Inc. (1953).

Where the use of a metal container is necessary, it is sometimes feasible to include a rust inhibitor in its contents to prevent leaking and container disintegration.

The inclusion of proprietary names anywhere herein does not imply an indorsement of brand or product, nor is the omission of any product intentional.

Consumers, dealers, pest control operators, and large scale users should obtain two pesticide booklets as follows:

1. Entoma, published by the Entomological Society of America. Address: Ellsworth H. Fisher, Dept. of Entomology, University of Wisconsin, Madison 6, Wis.
2. Pesticide Handbook, by D. E. H. Frear, State College, Pennsylvania.

Requisites of Application

HOW to begin: If spraying trees or crops, ascertain the *size* of the area in acres or in number of square feet. The next step is to arrive at a *dosage* rate per unit area. Dosage will depend on the chemical, the pest, the kind and density of growth, the proportion of spray that may be wasted, whether spraying is done in the dormant or the foliar period, and the type and efficiency of the spray machines. The final *volume* of spray per acre and for the total area can then be arrived at according to information, data, and quotations made in Chapters II, III, IV, and V for different types of equipment when treating various trees, shrubs, turf, fields, and crops.

Therefore, when applying concentrates for control of given pests, calculate the quantity of pesticide that would be applied by the conventional dilute spray method per 100 square feet, 1,000 square feet, per tree, per row, or per acre, depending on the unit of area. Then mix it with the necessary ingredients to make a given volume of concentrate. The volume of final mixture to use per unit area will vary according to the factors just mentioned that regulate dosage. For example, a given quantity of DDT may be effective at rates ranging from ½ to 2 gallons of finished spray per acre for gross feeders and active insects. Many other insecticides and fungicides may be applied at given rates in 4 to 10 gallons per acre of finished spray. For more dilute concentrates a volume of 12 to 15 gallons per acre may be preferable. A large shade tree that requires one pint of DDT concentrate per tree for cankerworm control may need 3 to 4 pints of lead arsenate concentrate. Large fruit trees may require ½ to 1½ gallons per tree or 15 to 30 gallons per acre.

Using conventional high pressure hydraulic sprayers in the northeastern United States, full grown apple trees (averaging 30 to 40 trees per acre) need 400 to 500 gallons (averaging 450) per acre per application, or 12 to 15 gallons per tree during the summer. During the dormant period 225 to 300 gallons per acre may be sufficient. Full grown peach trees need 4 to 6 gallons per tree when fully foliated, or slightly less per acre (300 to 400 gallons) than for apples. Grapes in foliage normally receive 200 to 350 gallons per acre. Deciduous woodlands require 500 to 600 gallons per acre and coniferous woodlands usually need 650 to 900 gallons per acre. Groups of trees require slightly less liquid per tree than isolated or open grown trees due to less foliage per tree and to less drift.

For some pests, particularly scales, mites, and aphids, that require fine atomization and complete coverage, slightly more toxicant is required than for the conventional method. On the other hand, in some other applications, the quantity of toxic ingredient applied per acre or per unit area should be reduced 20 to 50 per cent below that applied by conventional methods. Notable examples are (1) the application of oils to dormant deciduous trees and (2) the repeated application of the same pesticides to fruit trees or other foliage in the form of several successive treatments, which causes a progressive build-up of deposits. This is especially true for highly tenacious residues and where sprayed trees, plants or foliage are mature or not rapidly growing. It is less applicable when the foliage is growing fast and the chemical rapidly decomposed or removed by weathering.

Toxicants for the home garden and the household should be procured ready mixed in appropriate containers.

General recommendations are not included for deciduous fruit trees and for vegetables because the different conditions that occur in different localities affect the timing and selection of materials. However, several Tables are included later that enable the user to readily convert for concentrate application any local experiment station or extension service schedules or recommendations.

For individual elm trees having average crown diameter and depth, the following volumes of DDT spray per tree may be required in elm bark beetle control to suppress the Dutch elm disease (D.E.D.)

Table 61. Quantities of spray to use in mist blowers and hydraulic sprayers for elm bark beetle control.

Height of tree (feet)	Gallons of dilute spray by hydraulic sprayer		Pints of concentrated spray by mist blower at 1.6 gpm	
	dormant	foliar	dormant	foliar
5 to 15	3	5	0.25	0.5
16 to 35	6	10	0.5	1.0
36 to 50	13	25	1.0	1.5
51 to 65	20	40*	1.5	2.0
66 to 80	30	50*	2.0	3.0
81 to 120	45	75*	3.0	4.0

Nozzle Tip Selection for Table 62

For tractor speed of 2 to 3 m.p.h., use No. 1 tip
For tractor speed of 3 to 4 m.p.h., use No. 1½ tip
For tractor speed of 4 to 6 m.p.h., use No. 2 tip
For tractor speed of 6 to 8 m.p.h., use No. 3 tip

Table 62. Quantities of spray to use in hydraulic sprayers on elms for (1) complete coverage and (2) coverage for defoliators.

Height of tree (feet)	For good coverage: Gallons of dilute spray by hydraulic sprayer		For defoliators: Gallons of dilute spray (foliar period)
	dormant	foliar	
5	1	1.5	1.0
10	2	3.5	2.5
15	4	7.5	6.0
20	6	12.5	10.
25	7	15.	12.
30	7.5	17.5	14.
40	10.	20.	17.
50	17.5	30.	23
60	22	40	30
75	33	50	40
90	45	70	55

Dilutions for Airplane Application of Concentrated Sprays. For airplane applicators to apply the proper dosage of toxicant per acre, mix as follows: For three gallons of spray per acre, mix according to dilution table above. For two gallons per acre rate, use ⅔ amount of water indicated in Table 62. For one gallon per acre, use ⅓ of amount of water indicated in dilution table.

Mixing Procedure

POWDERED insecticides are ordinarily added directly to the water, which may or may not contain a wetting agent. Oil, or relatively nonvolatile coating liquid adjunct, is added last while stirring or agitating. If oil is the carrier instead of water, the insecticide is added directly to the oil. To form an emulsion of an insecticide dissolved in an oil solvent (as DDT in benzene), an oil-soluble emulsifying agent like Triton X-100 is stirred into the solvent. This solution is then added to sufficient water to give the insecticide concentration and volume desired in the finished spray. When a step in the sequence of mixing procedure requires the mixing of a small volume of material with a larger volume of material (liquid, powder or both), the smaller quantity (or volume) is added to the larger quantity, instead of adding the larger one to the smaller one.

When the sticker is either casein or Casco glue,* triethanolamine or ammonia is added to the water, the powdered casein product is then stirred in and agitated until it dissolves completely. The insecticide is then added. The adjuncts are used in the proportion by weight of 0.1 part of casein and .02 part of triethanolamine per part of solids to be added to the mixture. Soluble casein in liquid form can now be purchased* and used in place of powdered casein. When drifting fine sprays sometimes 0.1 to 0.15 pint of non-volatile (mineral oils, glycerine, triethylene glycol "Carbowax"** etc.) liquid is added to mixtures containing casein as the sticker to prevent too rapid evaporation.

The addition of solids to a liquid, whether they become dissolved or not, increases the volume of mixture 0.2 to 0.35 pint per pound of solids added, depending on the physical and chemical properties of the material. (Table 65)

The preparations of Table 65 (pages 382-385) are the highest concentrations that were prepared. The concentration can be reduced by adding more carrier. In some mixtures the principal carrier is

---

* Manufactured by Casein Company of America, 350 Madison Ave., New York, N. Y.

** "Carbowax" is manufactured by the Carbide and Carbon Chemicals Corporation, 30 East 42nd Street, New York 17, N. Y.

For mist blower and helicopter application

Table 63. Dosages of 6 per cent DDT solution or emulsion required for control of various insects in the Northeastern States, and timing of application (100X concentration) Nozzle output: 0.5 G.P.M.[a]

Insect	Quarts per tree of indicated height							Timing for
	10-20 feet	20-35 feet	35-50 feet	50-65 feet	65-80 feet	80-120 feet	gals./acre	Northeastern States
Gypsy moth	⅛	¼	¼	½	1	1	2	April 20 to June 10
Brown-tail moth	¼	½	1	—	—	—	2	April 25 to May 20, Aug. 10 to 25
White-marked tussock moth	¼	½	1	1	1½	2	2	When eggs begin to hatch.
Eastern tent caterpillar	⅓	½	1	1	1½	2	2	April 5 to June 1
Forest ten caterpillar	⅛	¼	½	⅔	1	1½	2	April 20 to June 7
Elm leaf beetle	¼	½	1	2	3	4		May 1 to June 15
Cankerworms	1/6	⅓	1	1	1½	2	2	April 25 to May 2
Japanese beetle	½	⅔	1	2	2	2	3	July 1 to 15, Aug. 15 to 20
May beetle	¼	½	⅔	1	1½	2	2	As soon as adults become abundant
Green-striped malpleworm	½	1	1	1	1½	1½	3	July 15 to 31
Orange-striped oakworm	½	1	1	1	1½	1½	3	Aug. 1 to Sept. 10
Spiny elm caterpillar	¼	½	½	1	1½	2	2	May 15 to June 15
Lace bugs on oak and sycamore	¼	½	⅔	1	2	3	2	As soon as nymphs are abundant.
Sawflies on pine	—	—	—	—	—	—	2	As soon as small larvae appear.
Mosquitos[b]	—	—	—	—	—	—	2	When adults appear.
Black flies[b]	—	—	—	—	—	—	2	When adults appear.

[a] For 200 X concentration, or 12% DDT, apply a total nozzle output of 0.3 g.p.m.

[b] Applies to areas where there is no DDT resistance build up.

water, while in others it is solvent and oil. Oil is less safe on most plants than water, much depending on the kind and volume of oil. Summer oil, at least, should be a highly refined, paraffin base white oil of not over 55 to 80 seconds Saybolt viscosity, and 90-100 per cent U.S.R. (Unsulfonated residue). In aerial application weight and volume are even more important than for ground dispersal, since cost of application is roughly proportional to the gross weight and volume per unit of toxicant material.

Wetting, Spreading, and Emulsifying Agents. Wetting agents, particularly water soluble ones, increase fluidity and atomization and reduce the quantity of water needed to make a fluid mixture. Also, spreaders increase the effectiveness of deposits of fungicides, but sometimes reduce ahesion. Wetting agents* commonly used include Santomerse D (powder), Santomerse S (liquid containing 33% Santomerse D), Ultrawet, Aresket, and Daxads No. 11 and No. 14, Igepons, and others. Oil soluble emulsifying agents or surfactants include Vatsol O.T. (70% soln.), Triton X-100, and other Tritons, Tweens (Nos. 20, 40 and 85), Emulphor D, Atlox 1045, Igepals and others. Suspending agents include Daxad No. 27, blood albumin, Wyoming bentonite, and methocel.

Some wetting agents and emulsifying agents work best in soft water mixture, while others are best for hard water. Some are combinations of several types for either acid, alkaline, or hard water. An excellent review of 700 trade name products has been made by McCutcheon (1955). No single agent is best for all conditions. In fact, there are so many agents that it is not possible to say which material is best for any specific mixture. Hence, the mention of a product by trade name does not necssarily imply an indorsement of that product.

Stickers. The most important adhesives are drying plant or animal oils such as soybean or fish oil, dissolved casein, Aroclor, Geon or VL600 (poly vinyl latex), polyethylene polysulfide (P.E.P.S.), and Wyoming bentonite plus powdered skim milk. Mineral oils (highly refined white oils) are sometimes added to the bentonite-milk mixture. Drying oils have two limitations (1) they may not be compatible with some materials, as lime-sulfur, and (2) if drying oil is the only non-volatile liquid present in a mixture, the fine droplets of water-borne sprays may dry out or harden after floating for some time in the air. Geon and P.E.P.S. are not stable or compatibe with some materials without the addition of certain

---

[3] See list of wetting agents and emulsifiers at end of Chapter V.

Table 64. Dilution table for cotton sprayers

(From: Cotton insect controls for 1954, Miss. Agr. Ext. Serv. Pub. 276)

Insecticide and No. of pounds in 1 gallon	Gallons emulsifiable concentrate	Gallons water	Pounds poison per acre, using 3 nozzles	Acres covered with number of nozzles per row		
				1 nozzle	2 nozzles	3 nozzles
2 lbs. Aldrin	1	23	0.25 lb.	24	12	8
2 lbs. Aramite	1	11	0.5 "	12	6	4
2 lbs. DDT	1	11	0.5 "	12	6	4
1.5 lbs. Dieldrin[a]	1	29[a]	0.15 "	30[a]	15	10
1.2 lbs. BHC	1	8	0.4 "	9	4.5	3
1.6 lbs. Endrin	1	23	0.2 "	24	12	8
2 lbs. Heptachlor	1	23	0.25 "	24	12	8
2 lbs. Methyl parathion	1	23	0.25 "	24	12	8
2 lbs. parathion	3½	50	0.10 "	50	25	17
2 lbs. Systox (Demeton)	1	23	0.25 "	24	12	8
6 lbs. Toxaphene	1	6.2	2.5 "	7.2	3.6	2.4
8 lbs. Toxaphene	1	8.6	2.5 "	9.6	4.8	3.2

[a] For *cutworm control* use ½ this amount of water and cover ½ number of acres shown in Table.

wetting or emulsifying agents. A good compatible adhesive in most cases is Wyoming bentonite two parts and powdered skim milk 0.5 part per 16 parts by weight of the insecticide-fungicide. Increasing the proportion of bentonite and skim milk will increase adhesion. The bentonite and skim milk are thoroughly dispersed in the water and the insecticide added last, or all the dry ingredients may be blended before adding water. A stock mixture of bentonite may be made by dispersing a pound of bentonite in two gallons of water and storing in an airtight container to prevent evaporation. The addition of oil to bentonite-skim milk increases adherence considerably.

Care should be taken to flush the spray tank between changes of mixtures because of chemical incompatibility and danger of plant injury. Materials like lime-sulfur, wettable sulfur, dichlone (2,3-dichloro 1,4-naphthoquinone), 100 per cent parathion liquid, or wettable DDT are not compatible with oils, and the spray tank should be thoroughly cleaned before changing from one type material to the other.

Foaming in the spray tank can be reduced somewhat by adding 1 to 2 pints of kerosene per 100 gallons of mixture.

The flash point and possible crystallization of some chemicals are factors to be reckoned with in storing and shipping some types of mixtures.

Formulas and Description of Concentrated Mixtures for General Use

Inorganic Insecticides

LEAD ARSENATE. ($PbHAsO_4$). Water is the primary carrier for lead arsenate but many mixtures contain 0.15 to 0.25 pint of oil or glycerin added either as an *adhesive* or to *prevent drying out* of the droplets. Stickers for lead arsenate include soybean oil, fish oil, cotton seed oil, Orthex, Spray Lastic, and skim milk powder. By adding 0.02 pound of Santomerse D or one fluid ounce of Santomerse S, or other suitable wetting agent per pound of lead arsenate, as much as 4 to 6 pounds of the arsenate can be incorporated in a gallon of mixture, depending on the brand. But, for ground application and often for aerial application lower concentrations are preferred. With all 14 brands of lead arsenate tested the use of suitable water-soluble wetting agents makes possible the preparation of fluid mixtures containing as little as one pound of water per pound of lead arsenate. Particle size and shape of the dry ingredients have an important bearing on the quantity of water necessary to produce a fluid mixture in high concentration. The wetting agent can be omitted in the preparation of mixtures containing less than 3½ pounds of lead arsenate per gallon of mixture.

Wettable DDT powder, sulfur, benzene hexachloride, basic copper sulfate, Ferbam, Zerab and various other compounds can be incorporated in lead arsenate mixtures.

CALCIUM ARSENATE ($Ca_3(AsO_4)_2$ or related chemicals). A maximum of 2.5 pounds of calcium arsenate can be included in a gallon of mixture. If oils or glycerin are added, it is advisable to *avoid violent agitation for long periods.* Dissolved casein is an effective adhesive as well as powdered casein which may be ground with the calcium arsenate. Two ounces of Wyoming bentonite plus ½ ounce skim-milk powder per pound of arsenical or combined insecticide-fungicide makes a good mixture. The bentonite should be dispersed thoroughly in water before adding the other ingredients. It may also be mixed dry as described previously. Other wettable powders such as DDT, sulfur, basic copper sulfate, parathion, and chlordane, as well as the liquid tetraethyl pyrophosphate may be incorporated if the mixture is applied while fresh.

CRYOLITE mixtures may contain up to 6 pounds of cryolite per gallon of mixture for aerial application if a wetting agent like Daxad No. 11 or Daxad No. 14 is added to reduce the quantity of water required. The addition of one pint of oil per five pounds of cryolite to the mixture will increase adhesion and reduce evaporation of fine sprays. Further dilution of the whole mixture can be made with water. Cryolite should not be used in mixtures containing lime.

Organic Materials

THE organic insecticides include oils, botanical poisons, and synthetic organic toxicants.

OIL CONCENTRATES. The refined, white oils and "Superior" oils, in viscosities ranging from 30 to 90 seconds Saybolt have several different uses in concentrated sprays. They include: (1) contact dormant sprays either as undiluted oil or as tank mixed, thoroughly agitated emulsions or miscible oils diluted to 20 to 40 per cent oil with water, (2) as a carrier (in part or wholly) for insecticides dissolved or suspended in it, (3) as extender, penetrant, spreader or sticker, and (4) to avoid complete volatilization of finely atomized droplets containing volatile components. The danger to plants must be considered in all applications of oil, and the quantity applied held to minimum requirements.

During the dormant period not over 6 gallons of oil per acre should be applied to fruit trees, nor more than 12 gallons per acre to deciduous woodlands. The usual dormant oil concentration applied in hydraulic rigs is three per cent oil. In airplane application the oil is usually applied undiluted, whereas in mist-blower application it may be applied as straight oil or diluted to 20 to 40 per cent with water. Stabilized emulsions or miscible oils are also safer than unstable or quick breaking emulsions or miscible oils. Injury decreases with decrease in color and aromatic content and with increase in paraffin chain structure, volatility, and unsulfonated residue. Fine atomization, the development of efficient, foolproof equipment and improved methods should reduce injury. Nicotine solution, malathion, and acaricides are often added to the oils.

P. J. Chapman and his coworkers have published some valuable work on spray oils, especially dormant types. One of these papers (Pearce, Chapman, and Avens, 1942) also gives a good list of references.

Botanical Organic Poisons

NICOTINE COMPOUNDS ($C_{10}H_{14}N_2$). Nicotine compounds tested were generally of three types: (1) Nicotine sulfate added directly to water or emulsion, (2) dual-fixed nicotine powder (as Black Leaf 155), and (3) nicotine alkaloid 97 to 99 per cent pure. The concentration and volume to apply will vary with the pest, volume of foliage, and other conditions. The 97 to 99 per cent alkaloid can be added directly to water or oil, or it can be added to the oil containing an oil-soluble emulsifier and then stirred into the water to form an emulsion. It cannot be mixed with oil-and-water without an oil-soluble emulsifier.

Two methods of using the nicotine as a stomach poison were employed. One method consisted of mixing a pound of dual-fixed nicotine powder (as Black Leaf 155) in two pounds of water containing two per cent *Santomerse D* or *S. Ultrawet*, or *Aresket* and then agitating with 0.4 pound of white mineral oil, giving four per cent nicotine in the final mixture. Further dilution with water can be made. It is better to add the fixed nicotine to the water than to reverse the procedure. The oil is added last. In the other method six fluid ounces of drying or semi-drying oil were included in formulas.

Nicotine sulfate and the nicotine alkaloid are compatible with a large number of insecticides and fungicides, including Bordeaux mixture. When the mixture is to contain oil and water, the nicotine alkaloid should first be stirred into the oil containing an oil-soluble emulsifier. Nicotine sulfate (Black Leaf 40) can be stirred directly into water, or into water containing a water-soluble or an oil emulsifier or wetting agent, if oil is present. It can also be added directly to emulsions containing chlorinated hydrocarbons like DDT, endrin, aldrin, etc.

Ground Derris, Cube, and Rotenone Extracts. Derris and cube are easily wetted with water containing wetting agents like *Santomerse* and *Ultrawet*. Without a wetting agent a minimum of 6 pints of water per pound of ground root is ordinarily required to make a fluid mixture, whereas with a wetting agent as little as 5 pints of water can be used per pound of derris or cubé, so that as much as 1.4 pounds of the powder can be included in a gallon of mixture. Derris and cubé can be mixed with DDT and sulfur to make a combination insecticide-fungicide mixture. Derris and cubé mixtures are compatible with most other insecticides, but should not be used with lime or strongly alkaline materials.

Emulsions of rotenone resins can be made by dissolving one part by weight of resins containing 25 per cent rotenone in 2 to 3 parts by weight of chloroform and adding this to water containing one part of Santomerse D per 20 parts of chloroform in the mixture to form a stable emulsion. The rotenone resins dissolved in chloroform can be added directly to oil. *This must be applied within 24 hours after preparation*, and cannot be added to water. Emulsifiable rotenone extracts containing up to five per cent rotenone can be purchased and are satisfactory for dilution with water. When applied in a straight oil, such as kerosene or horticultural base oil, the application must be made within 24 hours after adding the rotenone solution to the oil. Usually 4 to 16 fluid ounces of the 5 per cent rotenone solution are used per gallon of mixture, depending on the quantity of rotenone to be applied per acre or unit area, and the volume of water to be used. A pint of five per cent rotenone extract is essentially equivalent to a pound of five per cent rotenone powder derived from derris or cubé. Emulsifiable rotenone extracts are available, containing any concentration of rotenone desired.

Pyrethrum and Allethrin Powder and Extract. Powdered pyrethrum suspensions may contain up to 1¼ pounds of pyrethrum powder without a wetting agent or 1.4 pounds with a wetter plus water and 4 or 6 ounces of oil to make a gallon of final mixture. Wetting agents increase the ease of mixing and fluidity of the mixtures. Without a wetting agent, a paste should first be made of the powder mixed with a little water before adding the rest of the water, as in the case of derris. Pyrethrum should not be used with materials containing lime.

Pyrethrum or allethrin extract, with or without synergists like piperonyl butoxide, can be incorporated in mixtures to provide any concentration of pyrethrins desired for application with either oil or water as the principal carrier. If the pyrethrins are in oil, an emulsifier must be added before mixing it with water. Dissolved DDT and other dissolved chlorinated hydrocarbons can be added to the mixtures. From 5 to 10 parts of piperonyl butoxide are used per part of pyrethrins to increase toxicity and reduce deterioration.

Synthetic Organic Insecticides

Chlorinated Hydrocarbons. The chlorinated hydrocarbons or organic chlorides constitute a group of relatively new insecticides. The 12 most important ones in this group so far are aldrin, benzene hexachloride and lindane, chlordane DDT, dieldrin, Dilan, endrin, heptachlor, isodrin, methoxychlor, Perthane, and toxaphene. BHC has a disagreeable musty odor which lindane does not have, but the latter is about twice as expensive as the former.

These chemicals may be formulated as solutions, emulsions, and suspensions. The solid or crystal form like DDT, BHC, and methoxychlor have to be finely ground for use with dry diluents (carriers) to make wettable powders which may also contain a wetting agent to facilitate mixing in water. To make wettable powders containing liquid forms like chlordane, the liquid is thoroughly mixed with a wettable powder diluent.

For mixing with oils, the solid forms may be dissolved in various solvents and oils like xylene and kerosene. If an emulsion is to be made, an oil soluble emulsifier must be added to the dissolved insecticide to permit thorough mixing with water. In most cases the emulsion and solutions are more adhesive and longer lasting and more effective than wettable powders and dusts. All of these compounds may be procured in liquid or powder form ready for dilution with oil or water to any concentration or pounds per gallon desired.

They are compatible with each other and with most other insecticides and fungicides, but there are exceptions. For example, concentrates containing oil and oil solvents are not compatible with lime sulfur, sulfur, DN compounds, and dichlone. Also, some of these compounds are decomposed to some extent by alkaline solutions containing soluble lime, magnesium and iron compounds. The loss of one chlorine atom from the molecule of any of the above chlorinated hydrocarbons may render the insecticide relatively non-toxic.

Some operators have had difficulty with stock solutions of DDT crystallizing out on cold days when the concentrates remained out-of-doors for several hours or more. In some cases this was due to using too little solvent to hold the DDT in solution at low temperatures. To remedy this problem two type formulas as follows have given good results:

		by weight
(1)	DDT	30%
	Xylene	60%
	Emulsifier (as Triton X-100)	3%
	Water	7%
(2)	DDT	32%
	Xylene	60%
	Emulsifier	3%
	Acetone	5%

Other solvents can be substituted for xylene in the above formulas if they hold as much or more DDT than xylene.

Foliage Burn from Use of Chlorinated Hydrocarbons. To avoid foliage burn, considerable care must be exercised in applying certain solvents, undiluted oils, and combinations of solvents and oils containing DDT and other chlorinated hydrocarbons. When finely atomized, petroleum ether, acetone, benzene, xylene, and drying oils are relatively non-phytotoxic. Refined kerosene, and some of the 33 to 42 seconds viscosity refined white paraffin oils like Socony's X-100 oil are very noticeably less phytotoxic than unrefined kerosene. The No. 2 fuel oil is somewhat less safe than kerosene. Heavy red engine oils are highly toxic to foliage. Coarse atomization, poor distribution, and too heavy application increase the injury hazard.

Oil and solvent phytotoxicity decrease with (1) increased volatility, (2) decrease in aromatic content, and (3) decrease in unsaturated compounds and color. Also, paraffin base oils are less phytotoxic than naphthalene base and asphalt base oils. Mixtures of oils and aromatic solvents (as kerosene or fuel oil with xylene) may cause more injury than a separate application of oil and solvent. For example, kerosene alone (or with DDT) was one-third as toxic to plants as a mixture of equal portions of kerosene and xylene. The most phytotoxic solvents are the non-volatile aromatics.

A great deal of information has been accumulated in notes and unpublished reports on the phytotoxicity of oils, solvents, and chlorinated hydrocarbons. A thorough coverage of this material would require a lengthy treatise. In the absence of such a treatise, the reader is referred to a paper by Clower and Matthysse (1954).

Organic Phosphates. There are several widely used and highly effective compounds in this group, including parathion, TEPP, EPN, and malathion. Most of them may be procured as liquids or as powders. These compounds are very toxic so that per acre dosages are low. Therefore, the number of pints or pounds needed per gallon of finished spray is not a limiting factor in aerial application. Some of these compounds are extremely toxic to people, while a few others (notably malathion) are much less dangerous to humans and warm blooded animals. Far more human injuries per million pounds of material applied have resulted from using the powdered form than from the liquid. Information supplied by experiment stations, spray schedules, and manufacturers should be followed in calculating correct dosages. Tables 61-74 may be used for converting from 1x concentration to concentrated sprays of given X concentrations and for determining the gallonage to apply.

TEPP hydrolyzes in water to produce solutions that are strongly acid. These are not toxic to insects but do corrode metals and tanks. It is not compatible with arsenicals, hydrated lime, nicotine, pyrethrum and rotenone, and its compatibility with fixed copper and dithiocarbamate fungicides is questionable. It can be used with sulfur and the chlorinated hydrocarbon insecticides.

Parathion, malathion, and EPN present much the same compatibility problems as TEPP, only to a somewhat lesser degree.

Delnav, a new phosphate pesticide offered by Hercules Powder Co., Wilmington, Del., is available as a dust or spray, and is suggested for control of leafhoppers, thrips, leaf miners, and mites of various types. It is also suggested for use on cotton pests.

Dinitro (DN) Compounds: (Dinitro-o-cresol; 2,4-Dinitro-6 cyclohexyl phenol) DNC, and DNOC compounds are for dormant application to hardy deciduous trees only. Oil increases the toxicity to both plants and insects in proportion to the quantity of oil and DN applied. Oil can be added to water-DN mixtures by first adding an oil soluble emulsifier to the oil. Such mixtures are unsafe, except for hardy dormant trees. DN-111 (dicyclohexylamine salt of dinitro-o-cyclo-hexyl phenol) is less toxic than other DN compounds. It can be used in light dosages as a summer acaricide on resistant plants where there is no danger of drift of the colored spray onto buildings. From 6 to 12 ounces of glycerin or triethylene glycol can be added per gallon of DN-111 and water mixture to prevent too rapid evaporation of fine droplets.

Caution: DN materials leave a yellow deposit on clothes, buildings, and other objects sprayed.

Miscellaneous Acaricides

ARAMITE, DMC (Dimite), and ovex (Ovotran) are useful acaricides that are not highly toxic to humans. They may be procured as emulsifiable liquids or as wettable powders. The addition of 4 to 8 ounces of glycerin or oil per gallon of mixture increases effectiveness. The above acaricides are compatible with a number of materials including lead arsenate, wettable chlorinated hydrocarbons, wettable sulfur, ferbam, ziram, nicotine sulfate, bentonite, and skim milk. They are not effective against insects.

Tartar Emetic: Tartar emetic (Potassium antimony tartrate) mixtures should be applied within a few hours after preparation, if possible, in order to avoid possible crystallization at the bottom of the container. Crystallization is apt to occur if the concentration is high when the temperature is low. From 10 to 12 pints of water are used to dissolve each pound of tartar emetic. Two pounds of sugar are then dissolved in two and one-half pints of water. Vigorous stirring is required. After being dissolved, the two ingredients are poured together with stirring. A minimum of three pounds of tartar emetic are usually applied per acre. A common mixture contains 0.5 pounds of tartar emetic per gallon. Tartar emetic is not used on deciduous fruits.

Caution: Tartar emetic is poisonous to humans and should not be taken internally.

Inorganic Fungicides

Sulfur Compounds: Wettable sulfur mixtures can contain as high as 5 to 6 pounds of sulfur per gallon of mixture for aerial application, but formulations of ½ to 2 pounds of sulfur per gallon are more generally used in ground application. The addition of other insecticides and fungicides to sulfur concentrates reduces the quantity of sulfur or other powdered material that can be incorporated per gallon. In concentrated spray formulations, wettable sulfur is compatible with many materials such as lead arsenate, rotenone powders, pyrethrum powder, pyrethrum extract, nicotine sulfate, wettable chlorinated hydrocarbons, bentonite, skim milk, and casein. As much as one pint of oil, glycol, glycerin, or Carbowax No. 1500 can be safely used per 5 pounds of wettable sulfur in the mixture, but a greater proportion of oil to sulfur is not safe on foliage. Drying oils are relatively inert when applied with wettable sulfur. Glycerin, glycols, *Yumidol* (a hexahydric alcohol), Triton B1956 and Carbowax No. 1500 have mixed well with all sulfur formulations in any proportions, and limited tests suggest that they are relatively safe on foliage. Dissolved casein and the bentonite-skim milk sticker are good sulfur adhesives, with and without the small quantities of oil just mentioned.

Sulfur pastes and flotation sulfur are not as easily prepared in certain formulations as wettable sulfur. They can be used in water alone, but will require more study before suggestions can be made for their use with other chemicals.

Sulfur seems to prolong the residual effectiveness of wettable DDT.

Lime-sulfur concentrate (CaS_4) in finely atomized form can be applied by mist blowers to shade and fruit trees and crops with or without further dilution. The addition of a non-volatile liquid avoids complete evaporation of the fine droplets in the air. Oil cannot be added, but, in repeated tests 4 to 8 ounces of glycerin or triethylene glycol per gallon of lime-sulfur reduced drying, increased spreading, and appeared not to increase foliage injury. Triton X-100, Igepal, and Triton B1956 can be added to increase spreading. A good, compatible spreader increases the efficiency of lime-sulfur. Polyethylene poly-sulfide is compatible with lime-sulfur.

Only about ⅓ to ¼ as much lime-sulfur should be applied in summer applications as in dormant applications. The mixture should be finely atomized. Until further information is gained it should be applied cautiously if trees are not dormant. Experiments may indicate that it is possible to increase the lime-sulfur concentration by removal of some of the water and thereby reduce the dosage and gallonage applied per unit of area.

Copper Compounds: *Basic copper sulfate (as "Microgel") Copper "A" compound, "Micronucop," etc., containing 34 to 52% Cu:* These compounds have been found compatible in mixtures with a large number of insecticides including oils, glycerin, glycols, dissolved "Carbowax," lead arsenate, calcium arsenate, ziram, wettable DDT, DDT emulsion, oil emulsions and miscible oils, derris, pyrethrum, cryolite, all the chlorinated hydrocarbon wettable powders and emulsions, casein, bentonite, skimmed milk, and certain other compounds. They have a great advantage over Bordeaux mixture in being compatible with more materials. They can be prepared in higher copper concentrations, require less water, and *avoid the use of lime.* Their adhesion is not as tenacious as Bordeaux unless an adhesive such as soybean oil or dissolved casein is incorporated.

"Coposil" (copper ammonium silicate) and *yellow and red copper oxides* in finely powdered form are compatible in concentrated spray mixtures with a large number of compounds and can be prepared in mixtures containing as much as three pounds of copper compound per gallon; however, best coverage with minimum dosage may be achieved with an increase in liquid volume applied and a proportionate decrease in copper per gallon of mixture. Copper oxides settle out rapidly and require good agitation. The adhesives used with basic copper sulfate may be applied with the three compounds just mentioned.

The two copper compounds above can be added directly to emulsions of white, refined 32° to 80° Saybolt S.U. mineral oil. They can also be dispersed in straight oil of the above specification by continuous vigorous agitation, but this method is limited for summer applications by the danger of plant injury. This danger can be minimized to some extent by selecting a volatile oil carrier like refined kerosene (as Deo-Base), Shell Oil No. 7, or Socony Company's isoparaffinic oil (SV-100). These oils vaporize shortly after reaching the plant. Hence, they do not penetrate the plant tissue for as long or as deeply as the non-volatile, non-drying oils. Copper residues left by this type of oil are not highly adhesive.
Caution: Do not use on peaches or apples.

Bordeaux Mixture: Since Bordeaux precipitates tend to thicken, the highest Bordeaux mixture concentration tried was one pound of copper sulfate and one pound of fresh, fine hydrated lime per gallon of mixture. For mist blowers either a 10X concentration of $1\frac{1}{4}$ gallons of water per pound of copper sulfate in the mixture is recommended, or an 8X concentration. For mixing, the copper sulfate is first completely dissolved in about ¼ of the total water while the lime is thoroughly agitated in ¼ to ⅓ of the total water. The two mixtures are then poured or pumped together into the remaining water, while agitating vigorously. The oil or adhesive is added last. The mixture tends to wear out pumps and clog fine orifice nozzles.

Caution: Do not use on peaches or apples.

Organic Fungicides

CAPTAN, glyodin, and dichlone are promising new fungicides not closely related. They are not compatible with summer oils nor with alkaline materials.

Dichlone (Phygon): Dichlone (2,3-dichloro-1, 4-naphthoquinone) is a very toxic fungicide and is applied at low dosages per tree or per acre. It mixes well with water. Glycerin, glycols and Carbowax No. 1500 and also bentonite with or without skim milk have been used in water suspensions of dichlone without causing injury to shade and forest trees. However, dichlone is quite toxic to some plants. Dichlone mixtures should be applied on an experimental basis if injury is likely to ensue. Dichlone will burn the face and hands of some people; so protection while spraying is highly desirable. This condition can be partially remedied by the inclusion of glycerin or glycols.

The dithiocarbamates include ferbam, ziram, maneb, nabam, and zineb. They are widely used and relatively safe on most plants. They can be applied with most of the new insecticides, including the chlorinated hydrocarbons, and the organic phosphates, but, the compatibility of ferbam and malathion is questionable. The dithiocarbamates are not compatible with hydrated lime nor other highly alkaline media.

Ferbam or Fermate (ferric dimethyl dithiocarbamate) is a light, fine, black powder. A wetting agent is helpful in the preparation of ferbam mixtures due to the difficulty with which it is wetted. Daxads Nos. 11 and 14 and certain other materials are satisfactory for this purpose. Ferbam is compatible with oils, glycol, glycerin, Carbowax No. 1500, arsenicals, and wettable chlorinated hydrocarbon powders. It may also be used in combination with sulfur.

Nabam (Dithane): Nabam (disodium ethylene bisdithiocarbamate) The liquid form is preferable to the solid form. It is compatible with water, glycerin, diethylene glycol and Carbowax No. 1500, but is not very compatible with oils. In general, nabam has not been as adhesive or as effective as copper compounds and ferbam. If used on apples some foliage burn may result.

One or more companies are preparing an adhesive mixture of ferbam and bentonite skim milk-oil all ready for dilution. They also have a general purpose mixture containing lead arsenate or some other compatible insecticide (see *Stickers,* p. 367). This avoids the necessity of purchasing the various ingredients separately.

Ziram (Zerlate): Zinc dimethyl dithiocarbamate mixtures are prepared exactly as the basic copper sulfate formulations. Ziram and zineb are compatible with a large number of other pesticides. As in the case of basic copper sulfate, wetting agents increase fluidity of mixtures and the quantity of fungicide that can be incorporated into a given volume of mixture. Casein and oils with a considerable portion of drying oil are the best adhesives for ziram and zineb. Zerlate is often alternated with ferbam or copper in the schedule of treatments for anthracnose and late blight of potatoes and tomatoes. Ziram can be used on peach trees but is not safe for apples because of fruit russet.

Agricultural Puratized: Commercial compounds contain 3, 5, and 6 per cent active ingredient as phenyl mercuri triethanol ammonium lactate. Puratized mixes directly with water but probably should not be used with oil. In dilute sprays it is normally used at the rate of ½ to 1½ pints per 100 gallons of water. The mixture can be improved by the inclusion of 3 to 6 ounces of glycerin per gallon of spray solution. For control of sycamore anthracnose, as much as ¾ pint of Puratized has been included in a gallon of mixture, but in fruit applications ½ to 1½ ounces per gallon of spray is sufficient. Heavy dosages may cause foliage injury.

Puratized and other organic mercuries like Coromerc, Phix, Tag, etc., should not be used with alkaline chemicals. They are poisonous and must be handled carefully.

Tables for Calculating Dosage, Mixture, and Gallonage

IN the studies of mixtures, over 2000 usable formulas were developed. Because it is not practical to list precise formulas for every condition, it was decided to construct a set of tables and figures to cover all conditions (Tables 65 to 73). Some of the tables list powders alone, while others include both powder and liquid.

Table 65 gives the actual quantity of toxicant per 100 gallons of full dilution (1X) spray in addition to listing the quantity of commercial pesticides per 100 gallons of 1X dilution, the percentage of toxicant in concentrates and wettable powders, and the quantity of toxicant per gallon of undiluted liquid.

Table 66 lists the quantities of actual insecticide toxicant to use per 100 gallons for given concentrations ranging from 4X to 100X.

Table 67 gives the amount of swell or increase in volume that results from the addition of each pound of solids. It also gives the number of pounds per gallon with and without a wetting agent; and the minimum quantity of water required to make a fluid sprayable mixture. For some materials like cryolite, arsenicals, and sulfur, the number of pounds that can be incorporated in a gallon of mixture is a very critical factor, especially in aerial application. It is most critical where several insecticides, fungicides, and nutrients have to be applied in the same mixture. The amount of total solids to apply often is as high as 50 pounds per acre. In the case of some brands it is possible to obtain a fluid sprayable mixture with less water than is given in the table, since the table is made up to include all brands.

Table 68 lists the quantity of commercial fungicide material for 100 gallons of mixture for concentrations of 1X, 4X, 6X, 8X, 10X, and 15X.

Table 69 shows the quantities of powdered and liquid pesticide to use for given dosage and concentration rates for one quart and one gallon lots. This table is primarily for research and extension employees and other professional and semi-professional workers.

Table 70. Gives the quantity of unpacked insecticide powder by volume for given weights for use when measuring with household utensils. The last column of the table also shows the number of pints of powder that are equivalent to one pound. Table 71 provides the same information for fungicides. All measurements are "leveled," not "heaped."

Table 72 gives the quantities of insecticides to use in making given concentrations for one quart and one gallon lots with household measuring utensils. Table 73 gives essentially the same information for fungicides.

Table 74 quotes the dilution quantities for 25 per cent concentrates in 100 gallons of finished spray mixture.

CAUTION: The information in these tables is to serve as a set of handy tools that the user can adapt to his particular needs by using simple arithmetic and common sense.

Table 65. The amount of commercial insecticide powder or concentration and the quantity of actual toxicant required per 100 gallons of (1X) full dilution spray.

Insecticide (P = powder, L = liquid)	Commercial product in 100 gals. of 1X concentration	toxicant In 100 gals. of 1X concentration	Percent toxicant in		Toxicant per gal. undiluted liquid pounds
			some wettable powders	undiluted liquid concentrates	
Aldrin	1¼ lbs. P. 1 pint L.	0.25 lb.	20	22.5	2
Allethrin	1 lb. P. 1 pt. L.	.01 lb.	1	1	1.3
Aramite	2 lbs. P. 1¼ pts. L.	5 ozs.	15	25	2
BHC	1 lb. P. 1 qt. L.	0.25	25	12	1
BL 40	1¼ pts.	0.5 pt.	—	40	4
Calcium arsenate	2½ lbs.	2.5 lbs.	undiluted	—	—
Chlorobenzilate, 90%	1 lb. P. 1 pt. L.	.25 lb.	25	25	2
Chlordane	1½ lbs. P. 1½ pts. L.	0.75 lb.	50	48	4
Chlorothion	½ pt. L. 1½ lbs. P.	.25 lb.	—	about 50	4

Table 65 (Continued)

Insecticide (P = powder, L = liquid)	Commercial product in 100 gals. of 1X concentration	toxicant In 100 gals. of 1X concentration	Percent toxicant in		Toxicant per gal. undiluted liquid pounds
			some wettable powders	undiluted liquid concentrates	
DDD (TDE)	3 pts. L.	0.75 lb.	50	25	2
	1 lb. P.				
DDT	1 qt. L.	0.5 lb.	50	25	2
Diazinon	1½ lb. P.	0.75 lb.	25	—	—
	1 lb. P.				
Dilan	1 qt. L.	0.5 lb.	50	25	2
	½ lb. P.				
Dieldrin	1¼ pts. L.	0.25 lb.	50	18.5	1.5 to 1.6
	1 lb. P.				
Dimite	1 pt. L.	0.5			
	1½ lbs. P..	0.25	50	25	2
DNOC; DNC	3 pts. L.	1.5	—	40	4
Elgetol	1½ qts. L.				
	1 lb. P.	1.5 lb.	—	40	4
Endrin	1 pt. L.	0.2 lb.	20 and 25	18.5	1.6
EPN 300	1 lb. P.				
Heptachlor	1½ lbs. P.	0.25	25	—	—
	1½ pts. L.	6 ozs.	25	23.4	2

Table 65 (Continued)

Insecticide (P = powder, L = liquid)	Commercial product in 100 gals. of 1X concentration	toxicant In 100 gals. of 1X concentration	Percent toxicant in		Toxicant per gal. undiluted liquid pounds
			some wettable powders	undiluted liquid concentrates	
Isodrin	1¼ pts. L.	.25 lbs.	25	18.5	1.6
Karathane	1½ lbs. P.	.375 lbs.	25	—	—
Krenite (powdered DNC)	1½ lbs. P.	1.5	25	—	—
Lead arsenate	2.5 lbs. P.	2.5 lbs.	—	—	—
Lime	3 lbs. P.		—	—	—
Lindane	1 lb. P. 1 pt. L.	.20-25 lb.	25	25	2 lbs.
Lethane 60	1 qt. L.	1 lb.	50	50	4 lbs.
Lethane 384	1 qt. L. 1½ lbs. P.	1 lb.	50	50	4 lbs.
Malathion	1½ pts. L. 1½ lbs. P.	1.5 lbs.	50	50	4 lbs.
Methoxychlor	3 pts. L.	0.75 lb.	50	25	2 lbs.
Nicotine (97-100%)	½ pt. L. 2 lbs. P..	0.5 lb. 1.0 lb.	—	97-100	8.3 lbs.
Ovex (Ovotran)	2 pts. L. 2 lbs. P.	0.5 lb.	50	25	2 lbs.

Table 65 (Continued)

Insecticide (P=powder, L=liquid)	Commercial product in 100 gals. of 1X concentration	toxicant In 100 gals. of 1X concentration	Percent toxicant in		Toxicant per gal. undiluted liquid pounds
			some wettable powders	undiluted liquid concentrates	
Parathion	1¼ pts. L.	4.8 ozs.	15	25	2 lbs.
	4 lbs. P.				
Perthane	2 qts. L.	1 lb.	25	25	2 lbs.
Phenothiazine	3 lbs. P.	3 lbs.	100	—	—
	1 lb. P.				
Pyrethrum	1 pt. L.	.01 lb.	1	1	.08125
Rotenone (cubé or	3 lbs. P.				
derris root)	3 pts. L.	.15 lb.	4 to 5	5	0.4 lb.
	2 lbs. P.				
Strobane	2 qts. L.	1.0 lb.	50	25	2 lbs.
	1 lb. P.				
Systox (Demeton)	1 pt. L.	0.25 lb.	25	21	2 lbs.
Tartar emetic	2 lbs.+sugar	2 lbs.	—	—	—
TEPP	½ pt.	.25 lbs	—	40	4 lbs.
	4 lbs. P.				
Toxaphene	⅓ gal. L.	2 lbs.	50	80	6 lbs.
Xanthone (Genicide)	2 lbs.	2 lbs.	—	—	—

Table 66. Quantities of actual insecticide toxicant to use per 100 gallons of mixture for given concentration.

Insecticide	Quantities of actual toxicant per 100 gallons for concentrations of								
	4X	6X	8X	10X	12X	15X	20X	40X	100X
Aldrin	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Allethrin	0.04 lb.	0.06 lb.	0.08 lb.	0.1 lb.	0.125 lb.	0.15 lb.	0.2 lb.	0.3 lb.	1.0 lb.
Aramite	1.25 lbs.	1.87 lbs.	2.5 lbs.	3.12 lbs.	3.75 lbs.	4.7 lbs.	6.25 lbs.	12.5 lbs.	31 lbs.
BHC (gamma isomer)	1.00 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs
BL40	2 pts.	3 pts.	2 qts.	5 pts.	3 qts.	7.5 pts.	5 qts.	2.5 gals.	6.25 gals.
Calcium arsenate	10 lbs.	15 lbs.	20 lbs.	25 lbs.	30 lbs.	37.5 lbs.	50 lbs.	100 lbs.	250 lbs.
Chlorobenzilate	1.0 lb. P. 1.0 pt. L.	1.5 lbs. P. 1.5 pts. L.	2.0 lb. P. 2.0 pts. L.	2.5 lbs. P. 2.5 pts. L.	3 lbs. P. 3 pts. L.	3.75 lbs. P. 3.75 pts. L.	5 lbs. P. 5 pts. L.	10 lbs. P. 10 pts. L.	25 lbs. P. 25 pts. L.
Chlordane	3 lbs.	4.5 lbs.	6 lbs.	7.5 lbs.	9 lbs.	11.25 lbs.	15 lbs.	30 lbs.	75 lbs.
Chlorothion	2 pts.	3 pts.	2 qts.	5 pts.	3 qts.	7.5 pts.	5 qts.	2.5 gals.	6.25 gals.
DDD (TDE)	3 lbs.	4.5 lbs.	6 lbs.	7.5 lbs.	9 lbs.	11.25 lbs.	15 lbs.	30 lbs.	75 lbs.
DDT	2 lbs.	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7.5 lbs.	10 lbs.	20 lbs.	50 lbs
Diazinon	3 lbs.	4.5 lbs.	6 lbs.	7.5 lbs.	9 lbs.	11.25 lbs.	15 lbs.	30 lbs.	75 lbs
Dilan	2 lbs.	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7.5 lbs.	10 lbs.	20 lbs.	50 lbs.
Dieldrin	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
(Dimite)	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
DNOC (DNC)	6 lbs.	9 lbs.	12 lbs.	15 lbs.	18 lbs.	22.5 lbs.	30 lbs.	60 lbs.	150 lbs.
Elgetol (liquid)	1.5 gals.	2.25 gals.	3 gals.	3.75 gals.	4.5 gals.	5.6 gals.	7.5 gals.	15 gals.	37 gals.
Endrin	0.8 lb.	1.2 lbs.	1.6 lbs.	2 lbs.	2.4 lbs.	3 lbs.	4 lbs.	8 lbs.	20 lbs.
EPN 300	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Heptachlor	1.5 lbs.	2.25 lbs.	3 lbs.	3.75 lbs.	4.5 lbs.	6 lbs.	7.5 lbs.	15 lbs.	37.5 lbs.
Isodrin	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Karathane	1.5 lbs.	2.25 lbs.	3.0 lbs.	3.75 lbs.	4.5 lbs.	5.6 lbs.	7.5 lbs.	15 lbs.	37.5 lbs.
Krenite	2.4 lbs.	3.6 lbs.	4.8 lbs.	6 lbs.	7.2 lbs.	9 lbs.	12 lbs.	24 lbs.	60 lbs.

Table 66 (Continued)

Insecticide	Quantities of actual toxicant per 100 gallons for concentrations of								
	4X	6X	8X	10X	12X	15X	20X	40X	100X
Lead arsenate	10 lbs.	15 lbs.	20 lbs.	25 lbs.	30 lbs.	37.5 lbs.	50 lbs.	100 lbs.	250 lbs.
Lime	12 lbs.	18 lbs.	24 lbs.	30 lbs.	36 lbs.	45 lbs.	60 lbs.	120 lbs.	750 lbs.
Lindane	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Lethane 60	4 lbs.	6 lbs.	8 lbs.	10 lbs.	12 lbs.	15 lbs.	20 lbs.	40 lbs.	100 lbs.
Lethane 384	4 lbs.	6 lbs.	8 lbs.	10 lbs.	12 lbs.	15 lbs.	20 lbs.	40 lbs.	100 lbs.
Malathion	6 lbs.	9 lbs.	12 lbs.	15 lbs.	18 lbs.	22.5 lbs.	30 lbs.	60 lbs.	150 lbs.
Methoxychlor	3 lbs.	4.5 lbs.	6 lbs.	7.5 lbs.	9 lbs.	11.25 lbs.	15 lbs.	30 lbs.	75 lbs.
Nicotine (97-100%)	2 pts.	3 pts.	2 qts.	5 pts.	3 qts.	7.5 pts.	5 qts.	2.5 gal.	6.25 gals.
Ovex (Ovotran)	2 lbs.	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7.5 lbs.	10 lbs.	20 lbs.	50 lbs.
Parathion	1.25 lbs.	1.87 lbs.	2.5 lbs.	3.15 lbs.	3.75 lbs.	4.7 lbs.	6.25 lbs.	12.5 lbs.	31.25 lbs.
Perthane	4 lbs.	6 lbs.	8 lbs.	10 lbs.	12 lbs.	15 lbs.	20 lbs.	40 lbs.	100 lbs.
Phenothiazine	12 lbs.	18 lbs.	24 lbs.	30 lbs.	36 lbs.	45 lbs.	60 lbs.	120 lbs.	300 lbs.
Pyrethrum	0.04 lb.	0.06 lb.	0.08 lb.	0.1 lb.	0.125 lb.	0.15 lb.	0.2 lb.	0.4 lb.	1.0 lb.
Rotenone (Powdered root or extract)	0.6 lb.	0.9 lb.	1.2 lb.	1.5 lbs.	1.8 lbs.	2.25 lbs.	3 lbs.	6 lbs.	15 lbs.
Strobane	4.0 lbs.	6.0 lbs.	8.0 lbs.	10 lbs.	12 lbs.	15 lbs.	20 lbs.	40 lbs.	100 lbs.
Systox (Demeton)	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Tartar emetic, (sugar to be added)	8 lbs.	12 lbs.	16 lbs.	20 lbs.	24 lbs.	30 lbs.	40 lbs.	80 lbs.	200 lbs.
TEPP	1.0 lb.	1.5 lbs.	2.0 lbs.	2.5 lbs.	3 lbs.	3.75 lbs.	5 lbs.	10 lbs.	25 lbs.
Toxaphene	8.0 lbs.	12 lbs.	16 lbs.	20 lbs.	24 lbs.	30 lbs.	40 lbs.	80 lbs.	200 lbs.
Xanthone (Genicide)	8.0 lbs.	12 lbs.	16 lbs.	20 lbs.	24 lbs.	30 lbs.	40 lbs.	80 lbs.	200 lbs.

Table 67. Swell caused by the addition of powdered pesticides, the quantity of water required to make a fluid mixture, and the pounds of wettable powder per gallon of mixture.

Pesticide	Swell per pound of solids added	Water per pound of solids		Highest concentration usable in aerial application[a]	
		with wetter	without wetter	Pounds per gallon	
				with wetter	without wetter
Insecticides	pint	pints	pints		
Aldrin	0.33	2.34	2.87	3.0	2.5
Aramite	.30	2.28	2.75	3.1	2.6
BHC	.25	2.60	3.08	2.8	2.4
Calcium arsenate	.25	2.71	2.95	2.7	2.5
Chlordane	.30	2.65	3.33	2.6	2.2
Cryolite	.16	1.17	1.84	6.0	4.0
DDD (TDE)	.30	2.66	3.03	2.7	2.4
DDT (50%)	.30	2.75	3.70	2.6	2.0
DDT (100% in solvent)	.34	—	—	—	—
Dilan	.30	2.55	3.33	2.8	2.2
Dieldrin	.33	2.87	3.67	2.5	2.0
Dimite	.28	2.77	3.35	2.6	2.2
DNOC (DNC)	.25	2.95	3.75	2.5	2.0
Heptachlor	.28	2.38	3.72	3.0	2.0
Karathane	.25	2.71	3.08	2.7	2.4
Krenite	.23	2.73	3.10	2.7	2.4
Lead arsenate	.25	1.35	2.03 to 2.95	5.0	2.5 to 3.5
Lime	.25	2.80	3.22	2.6	2.3
Lindane	.25	2.71	3.38	2.7	2.2
Malathion 25%	.30	2.90	3.70	2.5	2.0
Methoxychlor (50%)	.30	3.33	3.70	2.2	2.0
Ovex (Ovotran)	.30	2.67	3.70	2.7	2.0
Parathion, 15%	.25	2.41	2.95	3.0	2.0
Pyrethrum	0.38	5.33	6.02	1.4	1.25
Rotenone (derris, cubé)	.40	5.31	6.02	1.4	1.25
Toxaphene (50%)	.35	2.85	3.32	3.0	2.5

Table 67 (Continued)

Pesticide	Swell per pound of solids added	Water per pound of solids		Highest concentration usable in aerial application[a]	
		with wetter	without wetter	Pounds with	per gallon without
Fungicides	pint	pints	pints	wetter	wetter
Captan	.30	2.7	3.33	2.7	2.2
Copper sulfate (basic copper)	.23	2.43	2.97	3.0	2.5
Copper oxide (fixed copper)	.15	2.51	3.05	3.0	2.5
Copposil	.20	2.46	3.00	3.0	2.5
Dichlone (Phygon)	.20	2.46	3.43	3.0	2.2
Ferbam	.35	3.65	5.65	2.0	1.5
Lime sulfur (powder)	.25	3.08	3.75	2.4	2.0
Maneb	.23	2.73	3.77	2.7	2.0
Sulfur (wettable)	.22	1.11	1.55	6.0	4.5
Zineb	.25	2.71	3.75	2.7	2.0
Ziram (zerlate)	.25	2.71	3.75	2.7	2.0

[a] Complete mix.—including wetter & sticker. [Also usable for figuring mixture]
[of several different pesticides.]

Common Weight and Volume Measurements

Powders: 1 ounce = 28.35 grams (gms)
16 ounces = 1 pound = 454 grams

Volume

Liquid: 1 ounce = 29.6 millileters (mls or c.c.)
16 ounces = 1 pint (⅛ gal.) = 473 millileters
1 quart = 32 ozs. = 946 mls., or ¼ gal.
1 gallon = 128 ozs. = 3785 mls.

Household measurements (volume):
1 teaspoonful = 4.9 mls = ⅓ tablespoon or ⅙ oz.
3 teas. = 1 tablespoonful = 15 mls.
2 tablespoonsful = 1 oz.
8 oz (236.5 mls) = 1 cup
2 cups = 1 pint

Liquid weight
1 gallon of water weighs 8.334 pounds
1 pint " " " 1.042 "

Table 68. Quantities of commercial fungicide for 100 gallons of mixture at given (X) concentrations.

Fungicide	Quantity of Material in Concentrations of					
	1X	4X	6X	8X	10X	15X
Bordeaux (blue vitriol-lime)[a]	6 lbs. C 4 lbs. L	24 lbs. C 16 lbs. L	36 lbs. C 24 lbs. L	48 lbs. C 32 lbs. L	not recom- mended	not possible
Bordeaux (dehydrated $CuSO_4$-lime)[a]	5 lbs. C 3.5 lbs. L	20 lbs. C 14 lbs. L	30 lbs. C 21 lbs. L	40 lbs. C 28 lbs. L	not recom- mended	not possible
Captan	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.
Copper (basic $CuSO_4$; 34 to 53% Cu)[b]	2.5 lbs.	10 lbs.	15 lbs.	20 lbs.	25 lbs.	37.5 lbs.
Copper oxide (fixed Cu)[b]	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.
Copposil[b]	2.5 lbs.	10 lbs.	15 lbs.	20 lbs.	25 lbs.	37.5 lbs.
Dichlone (Phygon XL)	½ lb.	2 lbs.	3 lbs.	4 lbs.	5 lbs.	7.5 lbs.
Ferbam (Fermate)	1.5 lbs.	6 lbs.	9 lbs.	12 lbs.	15 lbs.	22.5 lbs.
Glyodin (Crag 341)	1.5 lbs.	6 lbs.	9 lbs.	12 lbs.	15 lbs.	22.5 lbs.
Karathane	1.5 lbs. 10 gals. D	6 lbs. 40 gals. D	9 lbs. 60 gals. D	12 lbs. 80 gals. D	15 lbs. 100 gals. D	22.5 lbs.

---

[a] C = copper sulfate L = Lime

[b] n the 1x concentration fixed and basic copper compounds are usually used at the rate of 1 to 2 pounds of metallic Cu per 100 gals.

[c] D = Dormant S = Summer

(Table 68 (Continued)

Fungicide	Quantity of Material in Concentrations of					
	1X	4X	6X	8X	10X	15X
Lime-sulfur Concentrate[c]	2.5 gals. S	10 gals. S	15 gals. S	20 gals. S	25 gals. S	—
Maneb	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.
Nabam (Dithane D-14 or liquid Parzate)	2 qts. + ¾ lbs. of $ZnSO_4$	2 gals. + 3 lbs. of $ZnSO_4$	3 gals. + 4½ lbs. of $ZnSO_4$	4 gals. + 6 lbs. of $ZnSO_4$	5 gals. + 7½ lbs. of $ZnSO_4$	7.5 gals. + 11.25 lbs. of $ZnSO_4$
Puratized (5% phenyl mercuri compound)	½ pt.	2 pts.	3 pts.	4 pts.	5 pts.	7.5 pts.
Streptomycin	100 p.p.m. or 1.3 oz.	5.2 oz.	½ lb.	11.5 oz. or 0.7 lb.	13 oz. or 0.8 lb.	20 oz. or 1.25 lbs.
Sulfur (wettable)	5 lbs.	20 lbs.	30 lbs.	40 lbs.	50 lbs.	75 lbs.
Vancide A	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.
Zineb (Dithane Z-78)	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.
Ziram (Zerlate)	2 lbs.	8 lbs.	12 lbs.	16 lbs.	20 lbs.	30 lbs.

---

[a] C = copper sulfate L = Lime

[b] In the 1x concentration fixed and basic copper compounds are usually used at the rate of 1 to 2 pounds of metallic Cu per 100 gals.

[c] D = Dormant S = Summer

Table 69. Quantities of powdered and liquid pesticide to use for given dosage and concentration rates for one quart and one gallon lots.

Quantity of insecticide in 100 gals. of dilute spray	Quantity of material per quart and per gallon for concentrations of:												
	1 X		8 X		10 X		15 X		20 X		40 X		100 X
	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.
0.25 lb.	.28 gm	1.14 gms	2.28 gms	9.08 gms	2.8 gms	11.4 gms	4.2 gms	17.1 gms	5.6 gms	22.8 gms	11.2 gms	45.4 gms	1 oz.
0.25 pt.	.3 ml	1.18 mls	2.36 mls	9.46 mls	3 mls	11.8 mls	4.5 mls	17.7 mls	6 mls	23.6 mls	12 mls	47.2 mls	1 oz.
0.5 lb.	0.568 gm	2.27 gms	4.56 gms	18.16 gms	5.7 gms	22.7 gms	8.55 gms	34 gms	11.4 gms	45.4 gms	22.8 gms	90.8 gms	57 gms
0.5 pt.	0.6 ml	2.37 mls	4.72 mls	23.65 mls	6 mls	23.7 mls	9 mls	35.5 mls	12 mls	47.4 mls	24 mls	94.8 mls	60 mls
0.75 lb.	0.85 gm	3.41 gms	6.8 gms	27.3 gms	8.5 gms	34 gms	12.75 gms	51 gms	17 gms	68 gms	34 gms	136 gms	85 gms
0.75 pt.	0.9 ml	3.55 mls	7.2 mls	28.4 mls	9 mls	35.5 mls	13.5 mls	53.2 mls	18 mls	71 mls	36 mls	142 mls	90 mls
1.0 lb.	1.14 gm	4.54 gms	9.12 gms	36.32 gms	11.4 gms	45.4 gms	17.1 gms	68.1 gms	22.8 gms	90.8 gms	45.6 gms	182 gms	114 gms
1.0 pt.	1.18 mls	4.73 mls	9.44 mls	37.84 mls	11.8 mls	47.3 mls	17.7 mls	71 mls	23.6 mls	94.6 mls	27.2 mls	189 mls	118 mls
1.25 lbs.	1.38 gms	5.68 gms	11.04 gms	45.44 gms	13.8 gms	56.8 gms	20.7 gms	85.2 gms	27.6 gms	113.6 gms	55.2 gms	227 gms	138 gms

Table 69 (Continued)

1.25 pts.	1.42 mls	5.91 mls	11.36 mls	47.28 mls	14.2 mls	59.1 mls	21.3 mls	88.6 mls	28.4 mls	118 mls	56.8 mls	236 mls	142 mls
1.5 lbs.	1.7 gms	6.81 gms	13.6 gms	54.5 gms	17 gms	68.1 gms	25.5 gms	102.2 gms	34 gms	136 gms	68 gms	272 gms	170 gms
1.5 pts.	1.8 mls	7.1 mls	14.4 mls	56.8 mls	18 mls	71 mls	27 mls	107 mls	36 mls	142 mls	72 mls	284 mls	180 mls
2 lbs.	2.28 gms	9.08 gms	18.16 gms	72.64 gms	22.8 gms	90.8 gms	34.2 gms	136 gms	45.6 gms	181.6 gms	91.2 gms	363 gms	228 gms
2.0 pts.	2.36 mls	9.46 mls	18.9 mls	75.7 mls	23.6 mls	94.6 mls	35.4 mls	142 mls	47.2 mls	189 mls	94.4 mls	378 mls	236 mls
3.0 lbs.	3.42 gms	13.62 gms	27.36 gms	109 gms	34.2 gms	136 gms	51.3 gms	204 gms	68.4 gms	272 gms	136.8 gms	544 gms	342 gms
3.0 pts.	3.54 mls	14.19 mls	28.32 mls	113.5 mls	35.4 mls	142 mls	53 mls	212 mls	70.8 mls	284 mls	141.6 mls	568 mls	354 mls
4.0 lbs.	4.56 gms	18.16 gms	36.5 gms	145.3 gms	45.6 gms	182 gms	68.4 gms	273 gms	91.2 gms	364 gms	182.4 gms	728 gms	456 gms
4.0 pts.	4.72 mls	18.9 mls	37.8 mls	151.2 mls	47.2 mls	189 mls	71 mls	284 mls	94.4 mls	378 mls	189 mls	756 mls	1 pint
5.0 lbs.	5.7 gms	22.7 gms	45.6 gms	181.6 gms	57 gms	227 gms	86 gms	340 gms	114 gms	454 gms	228 gms	908 gms	570 gms
5.0 pts.	5.9 mls	23.65 mls	47.2 mls	189.2 mls	59 mls	236 mls	88.5 mls	354 mls	118 mls	1 pint	236 mls	1 qt.	590 mls

Table 70. Quantity of insecticide powder by volume for given weights, when measuring with household utensils.

Insecticide powder	Approximate volume to weigh		Ratio of weight of water to equal volume of powder
	One ounce level	One pound level	
Aldrin, 20% WP	5 tbsp.	5 cups	1:2.5[a]
Aramite, 15% WP	4 tbsp.	4 cups	1:2
BHC, (gamma isomer) 25%	4 tbsp.	4 cups	1:2
Calcium arsenate, 100% WP	5 tbsp.	5 cups	1:2.5
Chlordane, 50% WP	3½ tbsp.	3½ cups	1:1.8
Cryolite	8 tsp.	2⅔ cups	1:1.3
DDD (TDE), 50% WP	5 tbsp.	5 cups	1:2.5
DDT, 50% WP	5⅓ tbsp.	5⅓ cups	1:2.7
Diazinon, 25% WP	5 tbsp.	5 cups	1:2.5
Dilan, 50% WP	4½ tbsp.	4½ cups	1:2.25
Dieldrin, 50% WP	4¾ tbsp.	4¾ cups	1:2.37
Dimite, 50% WP	4¾ tbsp.	4¾ cups	1:2.37
DNOC Krenite, DNC, 40% WP	4 tbsp.	4 cups	1:2
Endrin, 25% WP	4¾ tbsp.	4¾ cups	1:2.37
EPN 300, 25% WP	5 tbsp.	5 cups	1:2.5
Heptachlor, 25% WP	4¾ tbsp.	4¾ cups	1:2.37
Isodrin, 25% WP	4½ tbsp.	4½ cups	1:2.25
Karathane, 25% WP	4 tbsp.	4 cups	1:2
Krenite, 25% WP	4 tbsp.	4 cups	1:2
Lead arsenate	4½ tbsp.	4½ cups	1:2.25
Lime, hydrated	3 tbsp.	3 cups	1:1.5
Lindane, 10 to 25% gamma isomer	4¼ tbsp.	4¼ cups	1:2.12
Malathion, 50% WP	4 tbsp.	4 cups	1:2
Methoxychlor, 50% WP	5½ tbsp.	5½ cups	1:2.75
Ovex (Ovotran), 50% WP	5 tbsp.	5 cups	1:2.5
Parathion, 15% WP	5 tbsp.	5 cups	1:2.5
Perthane, 25% WP	5 tbsp.	5 cups	1:2.5
Pyrethrum, 1% WP	5½ tbsp.	5½ cups	1:2,75
Rotenone (cubé or derris) 4 to 5%	6 tbsp.	6 cups	1:3
Strobane, 50% WP	5 tbsp.	5 cups	1:2.5
Systox, 25% WP	4¾ tbsp.	4¾ cups	1:2.37
Tartar emetic	6½ tsp.	2.17 cups	1:1.1
Toxaphene, 50% WP	3¼ tbsp.	3¼ cups	1:1.62

[a] In other words, 2.5 cups of the Aldrin powder were required to weigh as much as one cup of water.

Table 71. Quantity of fungicide powder by volume for given weights, when measuring with household utensils.

Fungicide	Approximate volume to weigh: One ounce level	Approximate volume to weigh: One pound level	Ratio of weight of water to equal volume of powder
Captan	4 tbsp.	4 cups	1:2[a]
Copper sulfate (basic)	2½ tbsp.	2½ cups	1:1.25
Copper oxide (fixed Cu)	2 tbsp.	2 cups	1:1
Copposil	2¼ tbsp.	2¼ cups	1:1.13
Dichlone (Phygon), 50% WP	3¼ tbsp.	3¼ cups	1:1.63
Ferbam (fermate)	7⅓ tbsp.	7⅓ cups	1:3.67
Dry lime-sulfur	3½ tbsp.	3½ cups	1:1.75
Maneb	4 tbsp.	4 cups	1:2
Sulfur, WP, flowers	3 tbsp.	3 cups	1:1.5
Sulfur, wettable	8 tsp.	2⅔ cups	1:1.3
Zineb	3¼ tbsp.	3 cups	1:1.5
Ziram (Zerlate)	3½ tbsp.	3½ cups	1:1.75

[a] In other words, two cups of Captan weighs the same as one cup of water.

Table 72. Dilution quantities for 25% concentration in 100 gallons of final spray mixture.[a]

Percentage concentration desired	Gallons of concentrate needed	Gallons of water or oil diluent for 100 gallons	Quantity of toxicant per gallon
			Pounds
.25	1	99	.021
.50	2	98	.042
1.00	4	96	.0833
2.00	8	92	.167
2.50	10	90	.21
4.00	16	84	.333
5.00	20	80	.417
6.00	24	76	.50
7.5	30	70	.625
10.0	40	60	.833
12.0	48	52	1.00

[a] To find the number of gallons required for a given quantity of toxicant per acre, divide the quantity of toxicant required per acre by the quantity of toxicant per gallon of finished spray. For example, 3 gallons of 4 percent solution will be required to give 1 pound of toxicant. (1 .333 = 3 gallons).

Table 73. Quantities of insecticides to use in making given concentrations for one quart and one-gallon lots with household measuring utensils.

Insecticide[a] & quantity in 100 gals. of 1X concentration	Quantity of material per quart and per gallon for concentrations of:								
	8 X		12 X		20 X		40 X		100 X
	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.
Aldrin (2 lbs. per gal.) 1 pt.	2 tsp.	2.25 tbsp.	1 tbsp.	3.8 tbsp.	5 tsp.	6.5 tbsp.	3.2 tbsp.	6⅓ ozs.	4 ozs.
Aldrin, 20% WP, 1¼ lbs.	1 oz.	4 ozs.	1.5 ozs.	6 ozs.	2.5 ozs.	9.4 ozs.	5 ozs.	18.8 ozs.	10 ozs.
Allethrin, 1%, 1 pt.	2 tsp.	1¼ ozs.	1 tbsp.	2 ozs.	2 tbsp.	3.8 ozs.	3⅔ tbsp.	7½ ozs.	4⅗ ozs.
Aramite, 15% WP, 2 lbs.	7 tsp.	5 ozs.	11 tsp.	7¼ ozs.	3 ozs.	12 ozs.	6 ozs.	3 cups	15 ozs.
Aramite, 25%, 1¼ pts.	2⅓ tsp.	3 tbsp.	2½ tsp.	4 tbsp.	1 oz.	4 ozs.	3¾ tbls.	1 cup	4¾ ozs.
BHC (10 to 12%) 2 pts. liquid	3½ tsp.	5 tbsp.	4½ tsp.	3 ozs.	3 tbsp.	6⅓ ozs.	3 ozs.	12 ozs.	1 cup
BHC 25% WP, 1 lb.	3½ tsp.	5 tbsp.	4½ tsp.	3 ozs.	3 tbsp.	6⅓ ozs.	3 ozs.	12 ozs.	1 cup
BL 40, 1¼ pts.	2⅓ tsp.	3 tbsp.	2½ tsp.	4 tbsp.	1 oz.	4 ozs.	3¾ tbsp.	1 cup	4¾ ozs.
Calcium arsenate 2.5 lbs.	3½ tbsp.	7 ozs.	5 tbsp.	10 ozs.	4¼ ozs.	17 ozs.	8½ ozs.	4¼ cups	5⅓ pts.
Chlorothion (liquid) ½ pt.	1 tsp.	5 tsp.	1½ tsp.	1 oz.	2½ tsp.	3 tbsp.	5 tsp.	3 ozs.	2 ozs.
DDD(TDE) [WP 1½ lbs.	1 oz.	4½ ozs.	1⅔ ozs.	6.8 ozs.	5⅔ tbsp.	1½ cups	5.7 ozs.	2.8 cups	14 ozs.
[3 pts.	1 oz.	4 ozs.	3½ tbsp.	5.7 ozs.	2⅓ ozs.	9½ ozs.	5 ozs.	19 ozs.	1½ cups
DDT [WP 1 lb.	5 tsp .	3¼ ozs.	7 tsp.	5 ozs.	2 ozs.	8 ozs.	4 ozs.	2 cups	10 ozs.
[2 pts.	3½ tsp.	5 tbsp.	4½ tsp.	3 ozs.	3 tbsp.	6⅓ ozs.	3 ozs.	12 ozs.	1 cup
Diazinon, WP, 1½ lbs.	1 oz.	4½ ozs.	1⅔ ozs.	6.8 ozs.	5⅔ tbsp.	1½ cups	5.7 ozs.	2.8 cups	14 ozs.
Dilan [WP 1 lb.	5 tsp.	3¼ ozs.	3½ tbsp.	5 ozs.	2 ozs.	8 ozs.	3½ ozs.	14 ozs.	9 ozs.
[Liquid 2 pts.	3½ tsp	5 tbsp.	4½ tsp.	3 ozs.	3 tbsp.	6⅓ ozs.	3 ozs.	12 ozs.	7½ ozs.
Dieldrin [WP ½ lb.	2 tsp.	9 tsp.	1 tbsp.	4⅓ tbsp.	5 tsp.	3½ ozs.	10 tsp.	7 ozs.	2 ozs.
[liquid 1¼ pts.	2½ tsp.	3 tsp.	3 tbsp.	2⅓ ozs.	1 oz.	4 ozs.	3¾ tbsp.	1 cup	4¾ ozs.

Table 73 (Continued)

Insecticide [a] & quantity in 100 gals. of 1X concentration	Quantity of material per quart and per gallon for concentrations of:								
	8 X		12 X		20 X		40 X		100 X
	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.
Dimite 25% emul., 1 pt.	2 tsp.	2¼ tbsp.	1 tbsp.	3.8 tbsp. 5½ ozs.	5 tsp.	6½ tbsp.	3.2 tbsp.	6⅓ ozs.	4 ozs.
DNOC (DNC) WP, 1½ lbs.	1 oz.	3⅔ ozs.	1½ ozs.	6 ozs.	2⅓ ozs.	9 ozs.	4½ ozs.	18 ozs.	11⅓ cups
Elgetol, 3 pts.	1 oz.	4 ozs.	1½ ozs.	5 ozs.	2⅓ ozs.	10 ozs.	5 ozs.	19 ozs.	1½ ozs.
Endrin WP, 1 lb.	4 tsp.	3⅓ ozs.	1 oz.	5 ozs.	2 ozs.	7½ ozs.	3½ ozs.	14 ozs.	10 ozs.
EPN 300 WP, 1 lb.	5 tsp.	3¼ ozs.	3½ tbsp.	6½ ozs.	2 ozs.	8 ozs.	3½ ozs.	14 ozs.	9 ozs.
Heptachlor, WP, 1½ lbs.	7 tsp.	4⅓ ozs.	1½ ozs.	5 ozs.	5⅓ tbsp.	10¾ ozs.	5.4 ozs.	21.5 ozs.	13½ ozs.
Isodrin WP, 1¼ lb.	5 tsp.	3½ ozs.	1¼ ozs.	10¾ tbsp.	2⅕ ozs.	8½ ozs.	4¼ ozs.	17 ozs.	11 ozs.
Karathane, 1½ lbs.	1 oz.	7 tbsp.	1½ ozs.	3⅓ tbsp.	2¼ ozs.	1⅛ cups	4¾ ozs.	2¼ cups	1½ cups
Krenite (DNC powder) ½ lb.	0.3 oz.	2½ tbsp. 6.3 ozs.	½ oz.	10.7 ozs.	0.8 oz.	6 tbsp.	1½ ozs.	¾ cup	4 ozs.
Lead arsenate, 2.5 lbs.	1.8 ozs.	12 tbsp.	2.7 ozs.	1¼ cup	4½ ozs.	2¼ cups	9 ozs.	4¼ cups	2¾ cups
Lime, 3 lbs.	1½ ozs.	5½ ozs.	2¼ ozs.	1 cup	3½ ozs.	1¾ cups	7 ozs.	3¼ cups	1¼ cups 7.8 tsp.
Lindane, 1 pt.	2 tsp.	2½ tbsp.	2¾ tsp. 3.6 tsp.	3¾ tbsp.	4.8 tsp.	6.3 tbsp.	5½ tsp. 19 tsp.	12½ tbsp.	2.6 tbsp.
Lethane 60, 2 pts.	3½ tsp.	5 tbsp.	1.2 tbsp. 3.6 tsp.	7.6 tbsp.	9½ tsp.	12½ tbsp.	6.3 tbsp. 19 tsp.	1½ cups	1 cup
Lethane 384, 2 pts.	3½ tsp.	5 tbsp.	1.2 tbsp.	7.6 tbsp.	9½ tsp.	12½ tbsp.	3 tbsp.	1½ cups	1 cup
Malathion, 50% WP, 1½ lbs.	1 oz.	7 tbsp.	1½ ozs.	10¾ tbsp.	2½ ozs.	1⅛ cups 29 tsp.	4¾ ozs.	2¼ cups	1½ cups 62tbsp.
Malathion, 50% emul., 1½ pts.	3 tsp.	11.3 tsp.	4.4 tsp.	17.3 tsp.	7.3 tsp.	9.6 tbsp.	14.6 tsp.	19 tbsp.	¾ cup

Table 73 (Continued)

Insecticide [a] & quantity in 100 gals. of 1X concentration	Quantity of material per quart and per gallon for concentrations of:								
	8 X		12 X		20 X		40 X		100 X
	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.
Methoxychlor, 50% WP, 1½ lbs.	1½ ozs.	10 tbsp.	2 ozs.	1⅞ cups	3¼ ozs.	2½ cups	6½ ozs.	5¼ cups	12 cups
Methoxychlor, 25% emul. 3 pts.	5¾ tsp.	7½ tbsp.	8.6 tsp.	10¾ tbsp.	14.2 tsp.	19 tbsp.	9½ tbsp.	2⅝ cups	1½ cups
Nicotine (97-100%) ½ pt.	1 tsp.	5 tsp.	1½ tsp.	6 tsp.	2¼ tsp.	3 tbsp.	4½ tsp.	6 tbsp.	4 tbsp.
Ovex (Ovotran) 25%, 2 pts.	3½ tsp.	15 tsp. 5 tbsp.	3.6 tsp. 1.2 tbsp.	22.8 tsp. 7.6 tbsp.	9.5 tsp. 3.2 tbsp.	37.8 tsp. 12.5 tbsp.	19 tsp. 6.3 tbsp.	25 tbsp. 1½ cups	15 tbsp. 2¾ cups
Parathion, 15% WP, 2 lbs.	1½ ozs.	¾ cup	2½ ozs.	1⅛ cups	4 ozs.	1⅞ cups	8 ozs.	3¾ cups	2¼ cups
Parathion, 25% emul., 1¼ pts.	2½ tsp.	9¼ tsp.	3½ tsp.	14 tsp.	2 tbsp.	8 tbsp. ½ cup	4 tbsp. ¼ cup	16 tbsp. 1 cup	9.8 tbsp.
Perthane, 25% emul., 4 pts.	2½ tbsp.	10 tbsp.	3¾ tbsp.	15 tbsp.	6¼ tbsp.	25 tbsp. 1½ cups	13 tbsp.	50 tbsp. 3⅛ cups	32 tbsp. 2 cups
Pyrethrum, 1% WP, 1 lb.	¾ oz.	3.3 ozs. 6.6 tbsp.	1¼ ozs.	5 ozs. 10 tbsp.	2.2 ozs.	8 ozs. 1 cup	4.4 ozs.	16½ ozs. 2 cups	1¾ cups
Pyrethrum, 1% emul., 1 pt.	2 tsp.	2½ tbsp.	2¾ tsp.	3¾ tbsp.	4.8 tsp.	6.3 tbsp.	1.8 tbsp.	12.6 tbsp.	4 ozs.
Rotenone, 5% WP, 3 lbs.	2.84 ozs.	1⅛ cup	4.3 ozs.	1⅝ cups	7.1 ozs.	2⅞ cups	14.4 ozs.	6¾ cups	4⅛ cups
Rotenone, 5% emul., 3 pts.	5¾ tsp.	7½ tbsp.	8.6 tsp.	10¾ tbsp.	14.2 tsp.	19 tbsp.	9½ tbsp.	2⅝ cups	1½ cups

Table 73 (Continued)

Insecticide[a] & quantity in 100 gals. of 1X concentration	Quantity of material per quart and per gallon for concentrations of:								
	8 X		12 X		20 X		40 X		100 X
	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.
Strobane, 25% emul., 4 pts.	2½ tbsp.	10 tbsp.	3¾ tbsp.	15 tbsp.	6¼ tbsp.	25 tbsp. 1½ cups	13 tbsp.	3⅛ cups	2 cups
Systox, 21% emul., 1 pt.	2 tsp.	2½ tbsp.	2¾ tsp.	3¾ tbsp.	4.8 tsp.	6.3 tbsp.	1.8 tbsp.	12.6 tbsp.	4 ozs.
TEPP 40%, ½ pt.	1 tsp.	5 tsp.	1½ tsp.	2 tbsp.	2¼ tsp.	3 tbsp.	4½ tsp.	6 tbsp.	4 tbsp.
Toxaphene, 6 lbs. per gal., ⅓ gal.	5⅓ tsp.	7 tbsp.	8 tsp.	10½ tbsp.	4¼ tbsp.	1 cup	8½ tbsp.	2¼ cups	1¾ cups

[a] In this column the powders are listed in pounds and the liquids are listed in pints.

Table 74. For use in measuring fungicides for one quart and one gallon lots with household measuring utensils.

Fungicide	Quantity of material per quart and per gallon for concentrations of:								
	1 X	6 X		8 X		10 X		15 X	
	100 gals.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.
Bordeaux (blue[a] vitriol-lime)	C 6 lbs. L 4 lbs.	C 1.8 oz. L 1¼ oz.	7 ozs. 6 ozs.	2½ ozs. 2 ozs.	9½ ozs. 6.4 ozs.	3 ozs. 2½ ozs.	1½ cups 1⅛ cups	—	—
Bordeaux (dehydrated $CuSO_4$-lime)	C 5 lbs. L 3.5 lbs.	C 1½ oz. L 1.1 oz.	6 ozs. 5 ozs.	2 ozs. 1¾ ozs.	8 ozs. 7 ozs.	2½ ozs. 2 ozs.	10 ozs. 8.3 ozs.	—	—
Captan	2 lbs.	1 oz.	3¾ ozs.	1¼ ozs.	5 ozs.	1½ ozs.	6¼ ozs.	2½ ozs.	1⅛ cups 9½ ozs.
[b]Copper (Microgel or basic $CuSO_4$; 34 to 53% Cu	2.5 lbs	¾ oz.	3 ozs.	1 oz.	4 ozs.	1¼ ozs.	4¾ ozs.	1¾ ozs.	7½ ozs.

Table 74 (Continued)

Fungicide		Quantity of material per quart and per gallon for concentrations of:								
		1 X	6 X		8 X		10 X		15 X	
		100 gals.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.	1 qt.	1 gal.
[a]Copper oxide; fixed copper		2 lbs.	½ oz.	2 ozs.	⅝ oz.	2⅔ ozs.	⅞ oz.	3 ozs.	1¼ ozs.	4¾ ozs.
[b]Copperosil		2.5 lbs.	0.6 oz.	2½ ozs.	1 oz.	3½ ozs.	1¼ ozs.	4¼ ozs.	1¾ ozs.	6¾ ozs.
Dichlone (Phygon XL)		0.5 lb.	1.1 tsp.	4½ tsp.	1½ tsp.	6 tsp.	2 tsp.	2⅔ tbsp.	2¾ tsp.	3⅔ tbsp.
Ferbam (fermate)		1.5 lbs.	1⅓	5⅓ ozs.	1¾ ozs.	7 ozs.	2 ozs.	8¾ ozs.	3¼ ozs.	13 ozs.
Glyodin, Crag 341 Liquid		1½ pts.	2¼ tsp.	8½ tsp.	2¾ tsp.	11 tsp.	3½ tsp.	4⅔ tbsp.	5¼ tsp.	6¾ tbsp.
Karathane		1.5 pts.	2¼ tsp.	8½ tsp.	2¾ tsp.	11 tsp.	3½ tsp.	4½ tbsp.	5¼ tsp.	6¾ tbsp.
Lime-sulfur[c]	D	10 gal.	2 cups	9 cups	3¾ cups	15 cups	undiluted		—	—
Conc	S	2.5 gal.	5½ tbsp.	2⅜ cups	7½ tbsp.	1⅞ cups	9½ tbsp.	2¼ cups	⅞ cup	4 cups
										1⅛ cups
Maneb		2 lbs.	1 oz.	3¾ ozs.	1¼ ozs.	5 ozs.	1½ ozs.	6¼ ozs.	2½ ozs.	9½ ozs.
Nabam										
(Dithane D-14 or						10 tbsp.		12½ tbsp.	4¾ tbsp.	19 tbsp.
liquid parzate)		2 qts.	2 tbsp.	7¾ tbsp.	2½ tbsp.	⅝ cup	3⅛ tbsp.	¾ cup		1-3/16 cup
Puratized (5% phenyl										
mercuri comp.)		0.5 pt.	¾ tsp.	3 tsp.	1 tsp.	1¾ tbsp.	1¼ tsp.		1¾ tsp.	2⅓ tbsp.
Streptomycin		1.3 oz.	0.54 gm	2.2 gm.	0.72 gm	2.9 gm.	0.92 gm.	3.7 gms.	1.35 gms.	5.5 gm.
						8⅓ ozs.		10 ozs.	4 ozs.	15 ozs.
Sulfur (wettable)		5 lbs.	1½ oz.	6 ozs.	2⅓ ozs.	1 cup	2½ ozs.	½ cup	1⅞ cups	1⅞ cups
Vancide A		2 lbs.	¾ oz.	3½ ozs.	1 oz.	4½ ozs.	1½ ozs.	5½ ozs.	2 ozs.	½ cup
Zineb		2 lbs.	¾ oz.	3 ozs.	1 oz.	3¾ ozs.	1¼ ozs.	4¾ ozs.	1⅞ ozs.	7 ozs.
Ziram (Zerlate)		2 lbs.	⅞ oz.	3⅓ ozs.	1 oz.	4½ ozs.	1½ ozs.	5½ ozs.	2 ozs.	8⅜ ozs.

---

[a] C = copper sulfate

[b] In the 1x concentration, fixed and basic copper compounds are usually used at the rate of 1 to 2 pounds of metallic Cu per 100 gals.

[c] D = dormant. S = summer L = Lime

Household Sprays

Concentrated sprays for flies, bedbugs, and cockroaches usually consist of a light, clear, volatile, deodorized kerosene-type oil to which has been added some toxic material, such as pyrethrins, rotenone, thiocyanates, DDT, lindane, or mixtures of these insecticidal agents. These sprays may be used undiluted as supplied by the manufacturer. Users of household sprays of the space type for flying insects such as flies, mosquitoes, and clothes moths should know that approximately ¼ ounce of liquid should be used to each 100 cubic feet of space, or four fluid ounces for a room 12 x 20 x 8 feet. The spray should be directed upward in the form of a fine mist, the doors kept closed for 15 to 30 minutes, and the fallen insects swept up and destroyed. A standard application of household spray of the residual type containing DDT should be at the rate of at least 200 milligrams of the primary toxicant per square foot of surface. This is equivalent to one quart of 20 per cent DDT, one-half gallon of 10 per cent DDT, or one gallon of 5 per cent DDT per gallon of spray to each 1000 square feet.

Compatibility

THE custom sprayer, pest control operator, farmer, or chemical salesman often wishes to know whether two chemicals may be combined safely in the spray tank. The two chief facts to know are: (1) will harmful substances be formed or liberated which may injure plants, and (2) will the value or effectiveness of the mixture against one or more pests be reduced? (Bailey and Smith, 1951).

Compatible Spray Materials: Numbers listed after name of a material indicate pesticides with which it may be combined. For example, lime-sulfur (No. 15) may be combined with No. 2 (aldrin, dieldrin, endrin, heptachlor), No. 13 (hydrated lime), No. 14 (lead arsenate), No. 19 (ovex), and No. 22 (sulfur). The chart does not indicate mixtures which are not compatible (Neiswander, 1955).

1. Aramite 2, 5, 6, 11, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25
2. Aldrin, dieldrin, endrin, and heptachlor 1, 3, 4, 6, 7, 9, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24
3. Bordeaux mixture 2, 7, 9, 14, 17, 19, 23
4. Captan 2, 5, 6, 7, 11, 14, 16, 17, 18, 19, 20, 21, 25
5. Chlordane 1, 4, 6, 7, 9, 11, 12, 14, 16, 18, 19, 20, 21, 22, 24, 25
6. DDT, TDE, BHC, and methoxychlor 1, 2, 4, 5, 7, 9, 11, 12, 14, 16, 18, 19, 20, 21, 22, 23, 24, 25

COMPATIBILITY

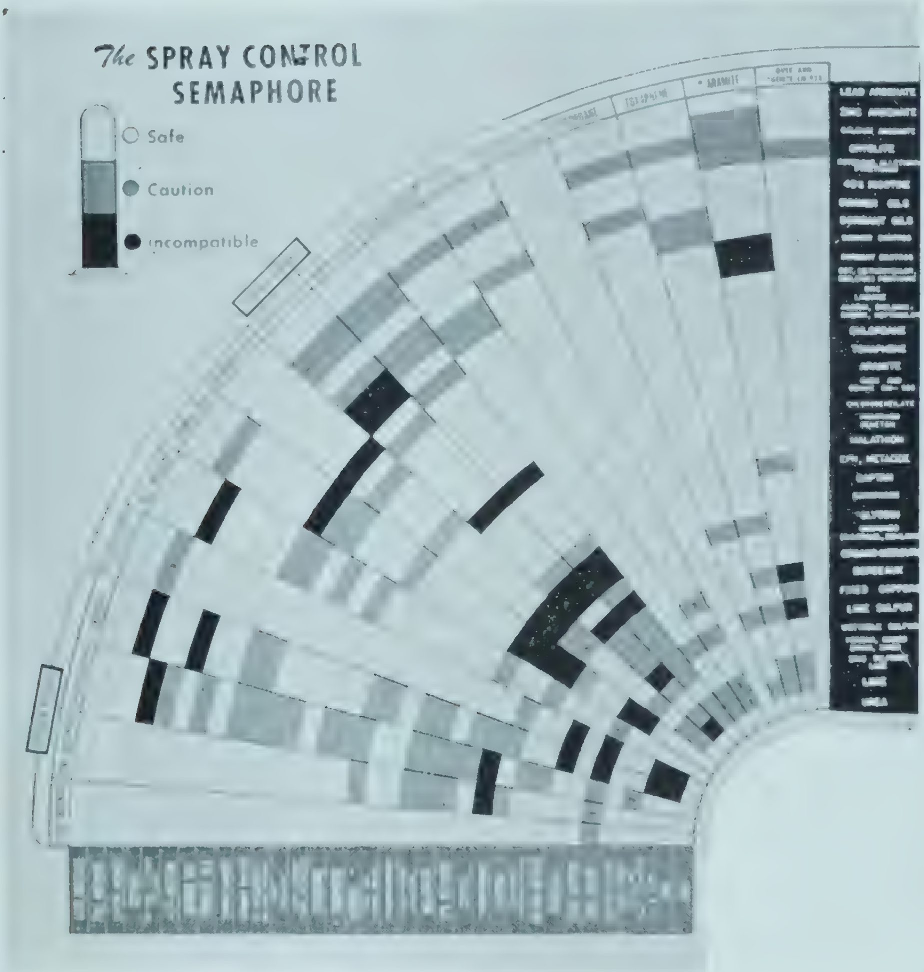


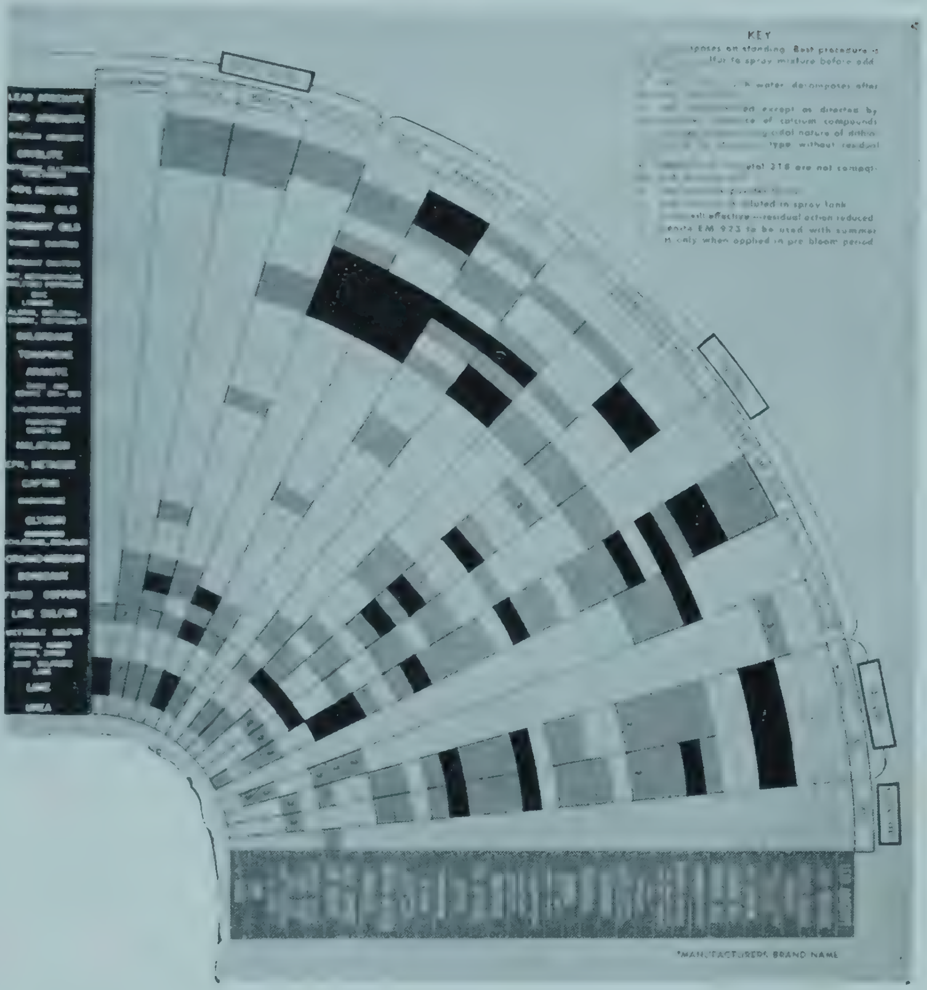
Figure 145—Spray Compatibility Chart

The *American Fruit Grower,* Willoughby, Ohio, offers a spray compatibility chart in three colors, illustrating the compatibility of some of the common insecticides. The reproduction on these two pages is too small to be of practical use, but the full size chart (11 x 17 inches) may be obtained by writing directly to the American Fruit Grower Company.

The code in the top right hand corner of the chart carries the following data; and refers to numbers inthe chart:

1. Decomposes on standing. Best procedure is to add lime sulfur to spray mixture before adding arsenical.
2. When mixed with water, decomposes after standing several hours.

SPRAY CHART



3. Not recommended except as directed by manufacturer. Presence of calcium compounds may change residual-fungicidal nature of dithiocarbamates to eradicant type without residual action.
4. *DN289 and *Elgetol 318 are not compatible with dormant oils.
5. Use wettable powder forms.
6. Add after oil is diluted in spray tank.
7. Initial kill effective—residual action reduced.
8. *Genite EM-923 to be used with summer dinitros only when applied in pre-bloom period.

7. DMC 2, 3, 4, 5, 6, 11, 13, 14, 16, 17, 20, 22, 23
8. DN-289 and Elgetol 318
9. Dormant oil 2, 3, 5, 6, 10, 17
10. Elgetol and Krenite 9
11. Ferbam, maneb, ziram, and zineb 1, 2, 4, 5, 6, 7, 14, 16, 17, 19, 20, 21, 23, 25
12. Fixed coppers 2, 5, 6, 13, 14, 17, 19, 20, 21, 22, 23, 25
13. Hydrated lime 2, 7, 12, 14, 15, 17, 19, 22, 23
14. Lead arsenate 1, 3, 4, 5, 6, 7, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23
15. Lime-sulfur 2, 13, 14, 19, 22
16. Malathion, demeton, EPN, and parathion 2, 4, 5, 6, 7, 11, 14, 19, 20, 21, 22, 24, 25
17. Nicotine sulfate 1, 2, 3, 4, 7, 9, 11, 12, 13, 14, 19, 21, 22, 23, 25
18. Organic mercury 1, 2, 4, 5, 6, 14, 19, 21, 25
19. Ovex 1, 2, 3, 4, 5, 6, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25
20. Phygon (Dichlone) 1, 2, 4, 5, 6, 7, 11, 12, 14, 16, 19, 21, 22, 24 (Use wettable powders)
21. Rotenone and pyrethrum 1, 2, 4, 5, 6, 11, 12, 14, 16, 17, 18, 19, 20, 22, 23, 25
22. Sulfur 1, 2, 5, 6, 7, 12, 13, 14, 15, 16, 17, 19, 20, 21, 24, 25
23. Summer oil 1, 2, 3, 6, 7, 11, 12, 13, 14, 17, 19, 21
24. TEPP and HETP 1, 2, 5, 6, 16, 19, 20, 22, 25
25. Toxaphene and Strobane 1, 4, 5, 11, 12, 16, 17, 18, 19, 21, 22, 24

Fertilizer and Nutritional Sprays

THE application of fertilizers as concentrated sprays promises to be one of the most forward steps taken in recent years in the progress of mechanized agriculture. Most, if not all, nutrients can now be handled in concentrated liquid form and can be applied by both ground and aerial equipment. Furthermore, it is now possible to obtain the benefit of these nutrients from applications to the *foliage* as well as to the *soil*. Most of the distribution has been by ground machines but aerial application is rapidly increasing. In 1955 about two million gallons of concentrated liquid fertilizer was sprayed by aircraft. (See Chapters III and IV.)

Another important feature is that most insecticides may be mixed with the liquid fertilizer to cut time, operations, and labor costs still further. Likewise, most weed and grass control chemicals can be added to the fertilizer solutions. A few highway departments are already applying fertilizers, seeds, insecticides, and mulch in the same operation.

This whole subject should be approached from the practical and scientific point of view. There are certain recommendations now available for the user. Many other things need further research and study. These include information on proper timing, number of sprays, dosage, optimum gallonage, and suitable application equipment. Other items on which additional information is needed relate to plant physiology and chemistry. These include the solubility and compatibility of the various combinations and mixtures of different chemicals: phytotoxicity; and chemical absorption by roots and foliage.

Soil applications differ from foliar applications in several respects. For example, soil applications are heavier. Often 300 to 800 pounds are applied per acre, representing about 28 to 75 gallons of spray concentrate, averaging about three pounds of fertilizer per gallon. A gallon may weigh approximately 10.6 pounds. Foliage applications do not require such high dosages and gallonages, but more frequent treatments are usually needed. To help select the best nutrient spray combinations and dosages, the grower should have the soil analysis, the appearance and production history of the plant, and an analysis of the foliage, seeds, and fruit.

Elements to Be Included in the Fertilizer

(From *Know Your Fertilizers,* 1952)

"Research has shown that plants require 15 different chemical elements for healthy growth. Twelve of these must come from the soil or from applied fertilizers, soil amendments, or nutrient sprays. They are:

Nitrogen (N)
Phosphorus (P)
Potassium (K)
Magnesium (Mg)
Manganese (Mn)
Copper (Cu)
Zinc (Zn)
Calcium (Ca)
Sulfur (S)
Boron (B)
Iron (Fe)
Molybdenum (Mo)

The other three—carbon, hydrogen, and oxygen—are provided by air and water."

Fertilizer Concentrates for the Soil

We may soon be ordering much of our fertilizer by the gallon instead of the bag. It's already happening in many areas where complete liquid fertilizers like 10-10-10 are being sold commercially for corn, wheat, and pasture land. Some farmers who have given them a trial join the research and commercial men who feel that liquid fertilizers offer many definite advantages.

One of the pioneers in this new development, John Strauss of Vincennes, Ind., is concentrating on 10-10-10 corn fertilizer and a 4-10-10 for use with anhydrous ammonia. (Laycock, 1954).

"We're not saying that a pound of liquid fertilizer is any better than a pound of solid plant food of the same formula," Strauss says; "we don't know that. But what's important is that liquids are so much faster to apply and easier to use. Once the plant food gets into the plant it's the same whether it came from a tank or a bag."

Liquids are currently being used more widely than ever before, and are approaching large-scale distribution. They measure up to the solids on every count, and pull well ahead in convenience and labor saving.

This development got its start in concentrate applications, leaf feeding, and liquid nitrogen tests. Now ways have been found to concentrate all of the essential plant foods in one liquid. They can be mixed in any of the common formulas and sold at a price in line with the costs of solids.

Farmers who are using the liquids point out these advantages:

1. Speed. You can fertilize 30 acres an hour using liquids. Counting hauling and turning time, the average is close to 20 acres an hour on most farms.

2. Effective in dry weather. Plants side-dressed with bands of liquid fertilizer take the plant food up immediately without rain or irrigation. Liquids also give a more uniform distribution of fertilizer materials. In one test, phosphorus was in leaves two feet above the ground within 15 minutes after application.

3. Easy handling. Some farmers handle bagged fertilizer four and five times before it is on the ground. Not so with liquids. Here small pumps and gravity do the work. In a recent test application, Commodore Osborne, Knox County, Indiana, sprayed 10 tons of 5-10-10 on 60 acres of corn stubble in part of an afternoon. This land was fall-plowed. The fertilizer cost him $50 a ton. "What I like about using liquid fertilizer," said Osborne, "is that now I

can fertilize by turning a valve instead of lifting and handling heavy bags. It used to take two of us to fertilize. Now one man can do it." Osborne puts the liquid down in a 40′ swath.

4. Price is right. The cost per pound of plant food is about the same in liquid as solid form to farmers around Vincennes. Cost of liquids is actually lower when you figure savings in time and labor. They are well suited to custom work.

5. Excellent for irrigation. These new wet fertilizers are the first ones completely adapted to use in irrigation systems. To give crops a "snack between meals," irrigation systems can be used for leaf feeding.

6. Low-cost equipment. Liquids can be spread from simple gravity or low-pressure-type rigs. Most farmers spraying them on pasture or stubble use small pumps and a fractional hp motor to build up about 40 lbs. pressure.

B. D. Alexander, Knox Co., Ind., mounted two 55 gal. drums on the sides of his tractor and used small trickle tubes to drop liquid 10-10-10 into the row on either side of the seed at planting time. The drums carried a half ton of fertilizer. The solution soaks into the ground beneath the seed and needs no special covering. Another grower combined liquid with anhydrous ammonia to side-dress corn. He ran trickle tubes down behind the same shoe that opened the furrow for the anhydrous.

Commodore Osborne applies the liquid directly from two 500-gal. tanks on his truck instead of reloading it into his tractor rig. A low-pressure pump forces the fertilizer through nozzles of a 40′ boom. This enables him to spread 1000 gallons, or six tons, of fertilizer without stopping.

Equipment for spreading the wet fertilizer is easily made. Farmers around Vincennes are constructing the spray booms from ¾ inch pipe. Dropping from this pipe are 1-inch sections of pipe with a cap over the end. Above the cap is a slot cut halfway through the pipe with a hacksaw. Fertilizer spreads in a film from this slot and forms into droplets before it hits the ground. (See Chapter III.)

Liquid fertilizers are easily handled in bulk right on the farm. All equipment needed for both storing and applying the plant food can be obtained for about $1000.

This includes a 6000-gal. steel or wooden storage tank and a tank trailer or a tank that can be lifted on and off a truck. These complete liquid fertilizers cause a little more corrosion and rust of the metal tanks than does plain water. The fertilizers are manufactured at full strength and aren't made to be diluted.

With liquids, as with solids, it's best to start with soil tests. But here are the suggested average applications for liquid fertilizers on major crops according to Laycock (1954):

"*Wheat.* Use 300 to 600 lbs. of 5-10-10 on soybean or corn stubble. Disk it in before seeding wheat. Then in the spring top-dress with 200 to 400 lbs. per acre of 12-8-6.

"*Corn.* Before plowing cornland, spray on 500 to 700 lbs. per acre of 8-8-8 or 10-10-10. Side-dress with another 40 to 80 lbs. of nitrogen. At planting time apply 150 to 200 lbs. per acre of 8-12-6 in the row.

"*Pasture.* In the fall spray 500 to 800 lbs. of 5-10-10. In the spring use the same amount of 8-8-8 or 10-10-10. If you are seeding a new pasture, plow down 600 to 800 lbs. per acre of 8-8-8 or 10-10-10 solution. Be sure the land is properly limed first."

Author's note: A number of fertilizer manufacturers were consulted for their opinions on the future for liquid fertilizers. Some of them thought they should wait and let the other fellow find out more about the facts and practicability of using liquids. Others were just not ready to shift over to the manufacture and distribution of liquids and would resist any quick change-over. Many recognized the great potentialities of liquid forms and some of them are already distributing, or preparing to distribute, liquids. The writer feels that liquids will never replace solids, particularly those materials that are too coarse to put out in liquid-type mixtures. However, the indications are that within a few years a big portion of fertilizers and nutrients will be applied in liquid concentrate form.

Foliage Application of Nutrients

Recently the interest in foliage application of nutrients has increased by leaps and bounds. (Pirone, 1952.) Fortunately this increased interest is not confined to amateur gardeners who are more prone than the commercial farmer to try new gadgets. New vegetable growers, orchardists, and foresters are becoming interested, and many professional arborists and nurserymen are using this relatively new method of spraying nutrients to trees and shrubs and, in the main, are securing excellent results.

For some years iron salts, particularly iron sulfate and iron ammonia citrate, have been used on azaleas, pin oaks, and pineapple with leaves yellowed by iron deficiency. Citrus growers know that a zinc spray will correct a lack of zinc in citrus leaves. Spraying pineapple foliage with urea is an effective method of feeding nitrogen to pineapple plants.

The first record of the application of nutrients in the form of atomized concentrated sprays was by Potts in 1930. These formulas (Potts, 1944) were 40X concentrations of ferrous sulfate and lime (4:1), zinc sulfate and lime, manganese sulfate and manganese borate. These mixtures were applied with and without lead arsenate and calcium arsenate. In some cases a weak Bordeaux mixture was added to supply the copper. The applications were very helpful to the health and growth of trees of many plant species in the tests, particularly those belonging to the genera *Prunus* and *Amygdalus.* Many of the mixtures were rendered effective for 75 days by the tenacious residues of gelatinous precipitate formed by an interaction between the dissolved sulfates and the calcium hydroxide. Since these residues were only slightly soluble on the foliage in dew and rain, it was possible to avoid foliage injury from the heavy dosages. In some mixtures soybean oil and linseed oil were added to increase adherence. When completely soluble copper sulfate and zinc sulfate were applied, the dose had to be drastically reduced to avoid foliage injury and, in addition, three or four applications were needed during the season for maximum results.

The increase in interest in this field is due primarily to four factors, one of the more important of which is the development of the concentrated spray method of application. This method is suited to the application of nutrients. Another is the development of nitrogen-bearing compounds, such as urea, which are far less toxic to foliage than those used in the earlier days. Methods of concentrating the essential elements into safe, liquid forms are being developed.

The third reason is the discovery that many of the elements essential for good plant nutrition can enter the leaves directly. This was not believed possible a dozen years ago. Today we know that nitrogen, potassium, phosphorus, magnesium, manganese, copper, zinc, and boron can all be taken into the plant through its foliage. Future research is expected to reveal that some of the other essential elements also can enter through the leaves and be used in the plants' food manufacturing processes.

A fourth reason is the research and publicity contributed by such commercial firms as the Ra-Pid-Gro Corporation of Danville, New York, a pioneer in foliage application of a complete chemical fertilizer, and by the DuPont Company, which developed and markets urea containing 43 per cent nitrogen under the trade name "NuGreen." *Ra-Pid-Gro* is a 23-21-17 completely soluble chemical fertilizer with minor elements added. The nitrogen is obtained from crystal urea, mono ammonium phosphate and potassium nitrate; the phosphoric acid from mono ammonium phosphate and mono potassium phosphate; the potassium from potassium nitrate and mono potassium phosphate.

Foliage feeding gives quick results where the problem involved is associated with nutrition. It should be borne in mind, however, that foliage feeding is not a cure-all for all plant and tree ills, nor is it a good substitute for good forest and shade tree practices. Moreover, the same ingredients in most foliage nutrient sprays now on the market will also do marvels when applied in solutions directly to the soil around trees, shrubs, flowers, vegetables, and on lawns.

The Pro's and Con's of Foliage Feeding

The points for and against foliar feeding are presented by Pirone (1952) as follows: "With three years of experience with foliage application of nutrients behind us, we would like to list the pro's and con's of the method.

The Case for Foliage Feeding

"The arguments for foliar feeding are:

"(1) Raw nutrients applied directly to the leaves become almost immediately available since they must travel a very short distance to get to the point where they are used by the plants to make plant foods.

"Consider for a moment how far these same raw nutrients must travel when applied to the soil. They must (if applied dry) first be dissolved in water. Then they must enter through the finer roots by the complicated process of basic exchange. Finally they must be transported through special tissues in the trunks and branches until they reach the leaves.

"(2) In early spring, when the soil is wet and cold, roots do not absorb nitrogen readily. With dry applications to the soil, therefore, many trees are denied this highly important element at a time when they need it most.

"(3) In midsummer dry spells, dry fertilizers in the soil cannot be used until moisture is available. Foliar sprays are immediately available.

"(4) Most of the phosphorus applied to the soil in the standard dry fertilizers is immediately fixed by chemical reactions and most of it is thus not immediately available to the tree. Hence we may have situations where one part of phosphorus applied directly to the leaves may do the work of ten or more parts applied to the soil.

"The same situation may occur with the minor elements. Zinc added to certain soils, for example, is unavailable because it is tied up in an insoluble form.

"(5) Under certain situations, as with trees planted in sidewalks or courtyards, where concrete, asphalt, paving blocks or flagstones cover their roots, foliage applications provide a rapid, inexpensive way of supplying the majority of necessary nutrients.

"(6) Foliage applications of nutrients can be made in conjunction with the regular insecticide-fungicide applications. Most of the prepared fertilizers advertised for use in foliage sprays are compatible with the newer organic fungicides and insecticides such as Fermate, DDT, and Parathion, as well as with the inorganic fungicide-insecticide, sulfur. These materials cannot safely be used with inorganics containing mercury and copper, however, because of the danger of precipitating some of the constituents of the fertilizers.

The Case Against Foliage Feeding

"(1) Foliar application of nutrients is not a complete substitute for soil applications under all conditions. In many cases it can only be a supplement to the nutrients taken in through the roots.

"(2) Many more foliar applications are needed per season than with soil treatment. One or two foliar applications are not enough to supply the tree's nitrogen needs for the entire season. Most trees will require four or five applications, starting after the leaves emerge in spring and repeating every two weeks. Trees which get some nitrogen from the soil, however, would require only two foliar applications.

"With minor elements like iron and boron, of which only traces are needed for normal growth, a single application in early spring may supply the tree's needs for the season.

"(3) There is more danger of burning from foliage sprays than with soil applications. This is true when the sprays are not diluted according to the manufacturer's directions. Urea, the prime source of nitrogen in most foliage spray preparations, may cause some leaf burn when the carbohydrate content of plants is low. The soil has a high buffering capacity and hence one can apply more than

Table 75. "Ra-Pid-Gro" Feeding Spray Guide for Vegetable Crops at 5 lb. Ra-Pid-Gro to 10 gal. water per acre.

Apply with sprayer or through irrigation system. May be combined with insecticides and fungicides.

Crop	When to spray
Asparagus	As soon as plants are up. Then every 10 days through cutting period.
Lima beans, snap beans	First feeding spray when plants are 4 to 6 in. high. Then every 3 weeks until pods start to form.
Beets, carrots, turnips and other root crops	First feeding spray when plants are 3 to 5 in. high. Then every 3 to 4 weeks until maturity.
Cabbage, cauliflower and broccoli	Use as a starter solution when planting and every 3 to 4 weeks until maturity.[a]
Cantaloupes, cucumbers pumpkins, squash and watermelon	First feeding when plants are 2 to 4 in. high. Then every 3 to 4 weeks until maturity.
Celery	Use as a starter solution when planting. Then every 3 weeks during growing season.
Corn (sweet)	First feeding when plants are 6 to 8 in. high. Then every 3 to 4 weeks until tassel stage.
Egg plant	Use as a starter solution when planting. Then every 4 weeks until maturity.
Peppers	Use as a starter solution. Feed again in 10 days and once more when in blossom.
Onions	Feed as soon as plants are up. Then every 3 weeks during growing season.
Lettuce	Spray as soon as plants are up. Then every 3 to 4 weeks until maturity.
Peas	First feeding when plants are 2 to 4 in. high and once more when in blossom.
Potatoes	As soon as plants are up and every 3 weeks during growing season. Can be used with insecticides and fungicides.
Spinach	Every 10 days after plants are up until maturity.
Tomatoes	Use as a starter solution when planting Then every 3 to 4 weeks until maturity.

[a] RA-PID-GRO Starter Solution - - Proportion 1 lb. to 20 gal. of water

the recommended amounts of dry fertilizers to soil without harming the plant.

"(4) Foliage nutrients are expensive. Part of this is due to the use of instantly soluble salts which are far more expensive than those used in standard soil fertilizers. Their cost is not prohibitive when one considers the excellent results obtained as well as the lower cost of application, as compared to soil treatment. The latter is especially true when the nutrients are included with the pest control sprays."

Foliage Feeding Tables

Tables 75 and 76 contain suggestions for using Ra-Pid-Gro. However, the grower may need to modify his treatments to satisfy

Table 76. Ra-Pid-Gro Feeding Spray Guide for corn, beans, small grains and hay crops amount to feed per acre at
4 lb. RA-PID-GRO in 10 to 20 gallons of water for ground spraying;
or 4 lb. RA-PID-GRO in 4 to 8 gallons of water for aircraft spraying.

Crop	When to spray
Corn	First spray when corn is 6 to 8 in. high and again when 24 to 36 in. high. Second feeding can be done in conjunction with corn borer spraying, mixing Ra-Pid-Gro with insecticide. May also be applied with weed killers.
Beans, Soybeans	Spray when plants are 4 to 6 in. high and again just before pods start to form.
Sorghum	Spray when plants are 4 to 6 in. high and again when plants are just beginning to head.
Oats, Wheat, Rye, Barley	Spray when plants are 3 to 5 in. high and again just before plants begin to head.
Alfalfa, clover, hay crops	First feeding early in spring when plants are 2 to 3 in. high. Second spray feeding when 4 to 6 in. high. Third feeding when blossoms first appear. Also feed after each cutting.
Pastures	Feed spray 3 to 4 times during growing season, depending on amount of cattle grazed.

his soil and plant conditions. The reference to Ra-Pid-Gro here does not mean an indorsement of that particular brand. Also, it is possible that cheaper and better combinations can be used than the ones referred to in this chapter.

Citrus Physiological Sprays Used in Florida

Nutrition.—Yearly applications of zinc in a nutritional spray are generally recommended for citrus groves in Florida, and manganese as well for groves on alkaline soil. Both are more effective when applied just before the spring growth. It is necessary to use copper for nutrition only when a deficiency actually exists and when this element is not used in a disease control program. Where boron deficiency is suspected, it is recommended that one pound of borax be applied with ¼ pound of hydrated lime per 100 gallons.

In making up sprays containing the sulfates of zinc, manganese and/or copper the following procedure should be followed: The sulfates should first be dissolved in the tank. Copper sulfate may be washed through the screen as the tank is filled, the agitator started, and the zinc sulfate and/or the manganese sulfate dusted into the tank slowly. After these are dissolved, the neutralizing agent, which may be either lime-sulfur or hydrated lime, is added. See formulas (Table 77) for quantities of lime needed to neutralize sulfates. One gallon of lime-sulfur or 3.2 pounds of dry lime-sulfur is equal in neutralizing capacity to one pound of lime.

No lime is required if neutral zinc, managanese or copper compounds are used. The quantity of neutral material to use, based on metallic content, is shown in Table 77. Zinc oxide should be used only in dormant sprays (Formula 1).

Molbydenum sprays are recommended to control yellow spot. Yellow spot generally appears in the summer and if the affected leaves are sprayed before October the yellow spots will regreen. Sprays applied in October or later will not regreen existing yellow spot, but will prevent it the following summer. Where yellow spot is mild, treatment with one ounce of sodium molybdate per 100 gallons is recommended, but in severe cases two ounces sodium molybdate can be applied with lime-sulfur, wettable sulfur, DN Dry Mix and Ovex, and copper, zinc and manganese. Sodium molybdate can be mixed with oil or parathion, but these combinations have not been thoroughly tested. It is suggested that molybdenum sprays be applied only to groves having yellow spot. Greasy spot should not be confused with yellow spot.

Maturity Sprays.—Lead arsenate or copper arsenate is used on grapefruit to reduce acidity. Use of arsenic on other citrus is illegal. The most effective use of arsenic is obtaind by spraying within 1 to 6 weeks after bloom. Lead arsenate is applied at the rate of 0.0-1.25 lb. of arsenate per 100 gallons, the lower amount for a high ratio of solids to acids in midseason and the higher amount for a high ratio in the early season. Basic copper arsenate may be used at 0.3-1 pound per 100 gallons where melanose control is also desired. It contains 0.41 pound copper per pound of material, and sufficient neutral copper should be added to bring up spray solution to 0.75 pound copper per 100 gallons. Calcium arsenate is not recommended, since it may cause leaf burn.

Preharvest Drop Control Sprays.—2,4-D (dichlorophenoxyacetic acid) or 2,4,5-TP (trichlorophenoxypropionic acid) compounds are effective for reducing preharvest drop of Pineapple and Temple oranges, and partially effective on seedling oranges. Sprays applied to other citrus varieties have been ineffective or inconsistent. Sprays containing 20 p.p.m. (acid equivalent) of either 2,4-D or 2,4,5-TP compounds are recommended for application separately or in combination with wettable sulfur, but only as dilute sprays. For best results, a single application should be made during October or November. If applied when succulent growth is present, some twisting of foliage may result. Unused spray solution should be discarded in a waste area. Spray machines should be thoroughly cleansed of these materials if they are to be used subsequently for spraying other crops or ornamentals. It is satisfactory to fill the tank about ⅓ full of water and add 2 lbs. of washing soda, agitate and then pump out through the guns, followed by rinsing with clean water.

Florida Citrus Sprays Schedule

Table 77 contains spray formulas for citrus with special reference to nutritional and physiological sprays taken from the 1955 *Better Fruit Program* of the Florida Citrus Commission, Lakeland, Fla. For more complete information see the complete schedule and the bulletin by H. J. Reitz, et al, (1954).

Schedule A is for producing fruit for fresh fruit market. This schedule provides for the control of scab, melanose, rust mite, purple mite, white fly and scale and the use of nutritional or physiological sprays. *Schedule B* is for producing fruit for processing. It provides for control of scale, whitefly, rust mite, purple mite; and for maturity sprays on grapefruit. For scab and melanose, Schedule A should be followed.

Table 77. Spray Formulas Applying To Schedules A and B

(Read general instructions of Florida Citrus Commission's spray schedule for further information on spray chemicals)

All quantities of materials are for 100 gallons of water

	lbs. per 100 gals.	
	dilute	concentrate *
Formula 1.		
Zinc sulfate	3	18
plus lime	1	6
or neutral zincs		
DN Dry Mix No. 1	0.7	4
or Aramite, 25%	2	12
or Ovex	1 to 1.5	6 to 9
Wettable sulfur	5 to 10	30 to 60
Supplements (if needed):		
Copper sulfate	3	18
plus lime	1.2	7.2
or neutral coppers		
Parathion (15% wet. powder)	1 to 1.7	8 to 10
Manganese sulfate	3	18
plus lime	0.1	0.6
or equiv. neutral forms		
Borax	1	2
Formula 2.		
Copper sulfate	3	18
plus lime	1.2	7.2
or neutral coppers		
Wettable Sulfur	5 to 10	30 to 60
Supplements (if needed):		
DN Dry Mix No. 1 (40% DN)	0.7	4
(if temp. is below 88° F.)		
or Aramite 25%	2	12
or Ovex	1 to 1.5	6 to 9
Parathion (15% wet. powder)	1 to 1.7	8 to 10
Zinc sulfate	3	18
plus lime	1	6
or neutral zincs		
Manganese sulfate	3	18
plus lime	0.1	0.6
or equiv. neutral forms		
Borax	1	2
**Lead arsenate (grapefruit only)	0.4 to 1.25	2.4 to 7.5

---

* These amounts for application at ⅙ dilute gallonage.

** For basic copper arsenate, see note under physiological sprays.

Table 77 (Continued)

	lbs. per 100 gals.	
	dilute	concentrate *
Formula 3.		
Oil	1.3%	10%
Neutral coppers	0.75	6.0
Supplement:		
**Lead arsenate (grapefruit only)	0.4 to 1.25	2.5 to 7.5
Formula 4.		
Oil	0.7%	
Parathion (15% wet. powder)	1	
Neutral coppers		
Supplement:		
**Lead arsenate (grapefruit only)	0.4 to 1.25	2.5 to 7.5
Formula 5.		
Oil (alone)	1.3%	10%
or oil	0.7%	5%
plus Parathion (15% wet. powder)	1	6
Supplement:		
**Lead arsenate (grapefruit only)	0.4 to 1.25	2.5 to 7.5
Formula 6.		
Wettable sulfur	5 to 10	30 to 60
Supplements (if needed):		
Aramite	2	12
or Ovex	1 to 1.5	6 to 9
Parathion (15% wet. powder)	1 to 1.7	8 to 10
Lead arsenate (grapefruit only)	0.4 to 1.25	2.4 to 7.5
Borax	1	2
Formula 7.		
Wettable sulfur	5 to 10	30 to 60
Supplements (if needed):		
Ovex	1 to 1.5	6 to 9
Lime-sulfur (liquid)	1 gal.	6 gal.
or Lime-sulfur (dry)	3 to 4	18 to 24
Lead arsenate (grapefruit only)	0.4 to 1.25	2.4 to 7.5
Borax	1	2
Formula 8.		
Parathion (15% wet. powder)	1 to 1.7	8 to 10
Wettable sulfur	5 to 10	30 to 60
Supplement:		
Lead arsenate (grapefruit only)	0.4 to 1.25	2.4 to 7.5

* These amounts for application at ⅙ dilute gallonage.

** For basic copper arsenate, see note under physiological sprays on page 414.

Table 77 (Continued)

	Lbs. per 100 gals.	
	dilute	concentrate *
Formula 9.		
Wettable sulfur	5 to 10	30 to 60
Supplements (if needed):		
Parathion (15% wet. Powder)	1.7	10
Aramite	2	12
or Ovex	1 to 1.5	6 to 9
Formula 10.		
Wettable sulfur	5 to 10	30 to 60
Lime-sulfur (liquid)	1 gal.	6 gal.
or Lime-sulfur (dry)	3 to 4	8 to 24
Supplement:		
Ovex	1 to 1.5	6 to 9
Formula 11.		
Wettable sulfur	5 to 10	30 to 60
Supplements (if needed):		
Parathion (15% wet. powder)	1 to 1.7	8 to 10
DN Dry Mix No. 1 (40% DN) (If temperature below 88°F)	0.7	4
or Aramite	2	12
or Ovex	1 to 1.5	6 to 9

Useful Data For Mixing Spray Formulas

Pounds of copper, zinc, and manganese compounds to equal the recommended dosage per 100 gal. of water.*

	Metallic content shown on label (%)						
	24-25	34-36	40	45	52-56	75	80
Copper	3.0	2.2	—	1.7	1.4	1.00	—
Zinc	—	3.0	—	—	2.0	—	1.4
Manganese	3.0	—	1.8	—	1.3	—	0.9

* For concentrate sprays, multiply the pounds required by 6.

Concentrated Spray Application of a Virus Disease To Control European Pine Sawfly

A few insect virus diseases may be spread in the form of concentrated sprays applied from the ground and from the air. Canadian entomologists successfully disseminated a virus disease of the European pine sawfly, *Neodiprion sertifer* (Geoff.) in Ontario in 1950 with sprays. The disease was made available for use in New Jersey in 1951. (Dowden, 1953). Complete sawfly control was obtained on a small area sprayed with knapsack sprayer, using dilute sprays. Excellent control was obtained in 1952 with concentrated sprays applied from the ground and from the air.

In the airplane application, about 2.5 billion polyhedra were used per gallon. One pint of glycerol was added per 3.5 gallons of spray. The glycerol helped prevent evaporation. Preliminary tests had shown that glycerol did not affect the potency of the spray. Application was at the rate of two gallons per acre.

A concentrated suspension of virus polyhedra can be obtained simply by placing diseased larvae in water and waiting for them to disintegrate. Indications are that a stock of disease virus can be stored for a long period of time for future use.

Literature Cited

Anonymous. 1952. Know your fertilizers. Fla. Agr. Expt. Sta. Bul. 506.

Anonymous. 1953. Warning Labels, Manual L-1, 3rd rev. Manufacturing Chemists Assoc., Inc., 246 Woodward Bldg., Washington 5, D.C.

Bailey, S. F. and L. M. Smith. 1951. Handbook of Agricultural Pest Control. Industry Publications, pp. 33-34.

Clower, D. F. and J. G. Matthysse. 1954. Phytotoxicity of insecticides in mist concentrate type formulations. *Jour. Econ. Ent.* 47(5):735-738.

Dowden, P. B. 1953. Use of a virus disease to control European pine sawfly. *Jour. Econ. Ent.* 46(3):525-526.

Fuller, H. C. 1940. Labeling. A few notes on the fundamentals of labeling soaps, insecticides, disinfectants, drugs, etc., pp. 145-150. MacNair-Dorland Co., N. Y.

Laycock, G. 1954. Spray your fertilizer. *Country Gentleman,* No. 8, p. 24.

McCutcheon, J. W. 1955. Synthetic detergents. *Soap and Sanitary Chem.* 25(8, 9 & 10).

Neiswander, R. B. 1955. Compatible spray materials. *Arborist's News* 20(2):15.

Pearce, G. W., P. J. Chapman, and A. W. Avens. 1942. The efficiency of dormant type oils in relation to their composition. *Jour. Econ. Ent.* 35(2):211-220, illus.

Pirone, P. 1952. Foliage application of nutrients. Natl. Shade Tree Conf. Proc., pp. 130-136.

Potts, S. F. 1944. Safened forms of calcium and lead arsenate. *Jour. Econ. Ent.* 37(2):314.

Reitz, H. J., C. J. Leonard, J. W. Sites, W. F. Spencer, I. Stewart, and I. W. Wander. 1954. Recommended fertilizers and nutritional sprays for citrus. Fla. Agr. Expt. Sta., Bul. 536, 15 pp.

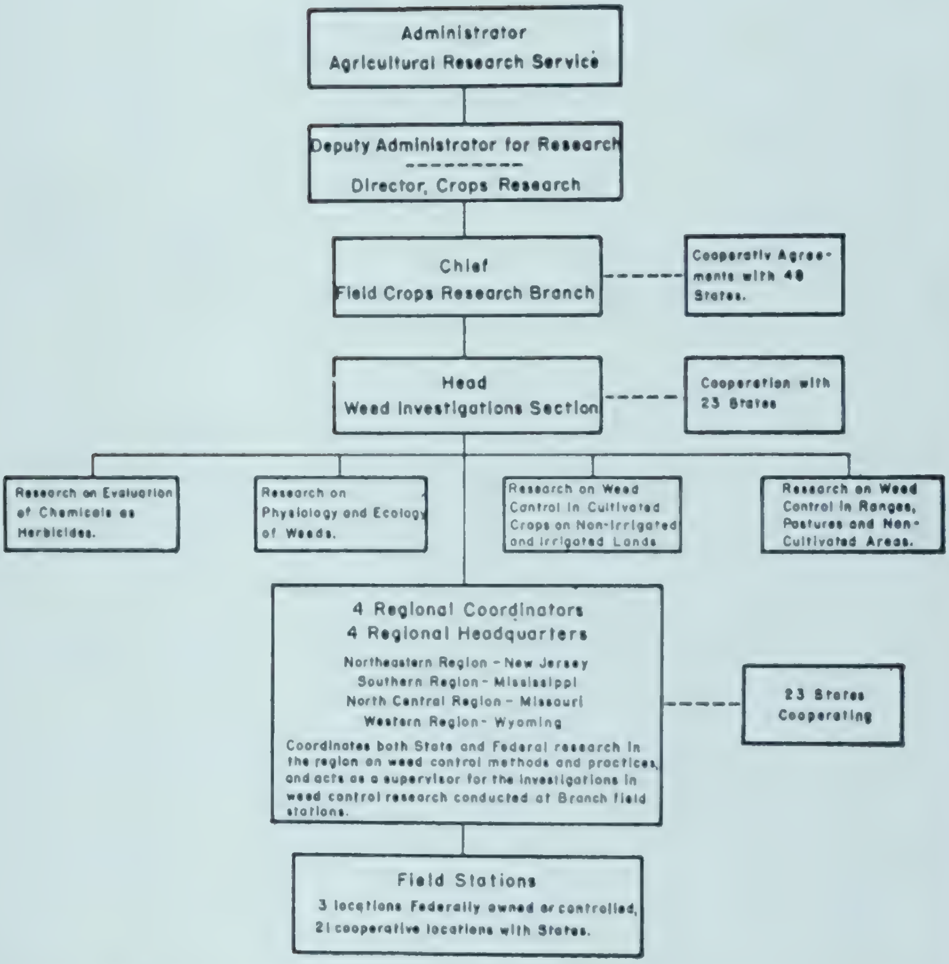

Administrator
Agricultural Research Service
Deputy Administrator for Research
Director, Crops Research
Chief
Field Crops Research Branch
Cooperativ Agreements with 48 States.
Head
Weed Investigations Section
Cooperation with 23 States
Research on Evaluation of Chemicals as Herbicides.
Research on Physiology and Ecology of Weeds.
Research on Weed Control in Cultivated Crops on Non-Irrigated and Irrigated Lands
Research on Weed Control in Ranges, Pastures and Non-Cultivated Areas.
4 Regional Coordinators
4 Regional Headquarters
Northeastern Region - New Jersey
Southern Region - Mississippi
North Central Region - Missouri
Western Region - Wyoming
Coordinates both State and Federal research in the region on weed control methods and practices, and acts as a supervisor for the investigations in weed control research conducted at Branch field stations.
23 States Cooperating
Field Stations
3 locations Federally owned or controlled,
21 cooperative locations with States.

Figure 146. Organization of the Weed Investigations section of the Field Crops branch of the Agricultural Research Service.

CHAPTER VI

CONTROL OF WEEDS AND WOODY PLANTS

Loss in money, resources, and health

A *WEED* is a plant growing where it is desired that something else shall grow. It does more harm than good and has a habit of intruding where not wanted. It includes undesirable herbaceous plants, grasses, shrubs, "brush" and trees, including certain forest trees under certain conditions.

Few people realize the extreme seriousness of weeds. Too many take weedy plants for granted as necessary evils that must be endured, and because of their universality do not appreciate the damage done. Weeds are among the greatest contributors to production costs on American farms. The losses caused by weeds on farms in the United States have now reached an estimated five billion dollars annually, with the average grower losing 10 per cent of the value of his products. These losses are estimated to equal the combined losses from insects and diseases and are second only to farm losses caused by soil erosion.

But that is only a part of the whole *weed* story. New chemicals and new application equipment and techniques are effecting a revolution in weed control. During the past four years over 30 million acres have been treated annually for weed and brush control. Chemicals are now being applied annually on one acre in every 10 acres of cultivated land for weed control. In 1954, it is estimated that over 85 million pounds of herbicides were used on agricultural and non-agricultural land. In 1952, about 70 per cent of the acreage sprayed was treated by the farmer at a cost of 26 million dollars for materials, using his own equipment. On the remaining 30 per cent of the total acreage, custom operators furnished and applied the herbicides for a total charge of about 22 million dollars. This does not include material and application costs for non-agricultural lands. Over 85 per cent of the above area was treated with concentrated spray.

Today there are around 240 million acres of brush-infested and waste land in the United States which are not producing profitably—acres which would give a net return with the right kind of weed and brush control program. Some of this area could be converted for forestry use. Other areas could be converted into improved grass land and erosion resistant areas.

The table below, prepared by Shaw (1955) lists the acreages treated in several crop categories. It does not include about 12 million acres that were treated in Canada.

Table 78. Some of the crops treated and the cost of chemical weed and brush control,[a] 1953.

Crop	Acres treated	Times treated	Percentage sprayed by		Cost per treatment acre	
			Farmers	Custom operators	Chemical cost	Custom operators rate
	1000 acres	number	percent	percent	Dollars	Dollars
Small grains[b]	17,012	1.04	63	37	.66	1.84
Corn (Zea Mays)	9,065	1.05	75	25	.69	1.86
Pasture and rangeland	2,192	1.14	64	36	1.09	2.60
Other crops[c]	2,629	1.37	77	23	4.22	—
Total	20,898	—	—	—	—	—

[a] Does not include the acreage of non-agricultural land such as highway, utility lines and railroads rights-of-way; and military and industrial sites treated for weed control.
[b] Includes wheat, oats, rye, barley, flax, and rice.
[c] Includes crops and land other than small grains, corn, and pasture.

Wilson (1944) wrote a splendid account of the nature of weed damage prior to 1955. His paper has 409 references. An excerpt of his paper is given below.

"Some weedy plants are poisonous to animals that consume them because they either contain poisonous compounds or produce poisons in the animal's digestive system. Most such losses occur in the western states where poisonous plants are more abundant than in the east. Injury of often as much as 8 per cent of Colorado's livestock results from the effects of more than 100 species of such plants. . .

"Many common weeds possess sharp structures as awns, spines, thorns or barbs which may cause mechanical injury to livestock. In certain areas of the West, sheep may have such sore mouths as a result of them that they are unable to eat. Frequently eye wounds results in partial blindness which prevents their finding feed. Certain types of needle grasses may become imbedded in the flesh of sheep, and this materially lowers the quality of the carcass. A few of the more common weeds producing mechanical injuries are wild oats (*Avena fatua* L.), wild barley (*Hordeum jubatum* L.), puncture vine (*Tribulus terrestris* L.), sandbur (*Cenchrus pauciflorus Benth.*), and species of *Xanthium* (cocklebur), *Cirsium* (thistle), *Centaurea* (Centaurea), *Aristida* (threeawn) and *Stipa* (Needlegrass).

"Some weedy plants impart undesirable flavors and odors to the dairy products of cows that eat them, and millions of dollars are thus lost each year. The more common weeds producing bad flavors are yellow "bitter" weed; and species of *Allium*, including wild onion, garlic and leek. The Frenchweed plant (*Thlaspi arvense* L.) produces a similar flavor. Other weeds which impart undesirable flavors to milk are pepper grasses, wild carrot, ragweeds, marsh elder, smartweeds, mustards and bitterweed (*Helenium tenuifolium* Nutt.) In some sections of the East wild garlic grows in wheat fields and the bulblets are harvested along with the wheat. Unless the bulblets are separated the garlic imparts a flavor to the flour, thus reducing its market value.

"Poison ivy (*Rhus toxicodendron* L.) and poison sumac (*Rhus vernix* L.) are examples of weedy plants which may cause a severe itching rash on the skin of most persons. Some people are resistant or immune, others are very susceptible. Much time is lost each year by those who are affected, and in some cases complications result in death. . . ."

Hayfever causes losses of millions of dollars each year and makes life somewhat miserable for about 10 million American citizens, or about one in every 16. About 80 per cent of the sufferers are affected by the pollen of common ragweed(*Amborsia elatior* L.). The causes for the remaining 20 per cent are divided among several grasses, tree pollen in the spring months, and other plants, in that order. Few areas of the country are free from ragweed pollen and these sections become havens of refuge during late summer when the plants are in bloom.

Weeds harbor numerous parasites and diseases. There is a relationship between weeds in cereals and development of root rots; and certain weeds harbor diseases of sugar beets, tobacco, and tomatoes. Some weeds are carriers of leaf-roll and rugose mosaic of potato, and the cotton root rot fungus, *Phymatotrichum omnivorum* (Sh.) Dug., lives on many species. There is also a relationship between weedy plants of Idaho and the curly top disease. Those are just a few of numerous cases that could be cited.

Weeds are a potent drain on soil fertility. Snidor (1940) analyzed 15 common species in central and northern Illinois. The percentage of nitrogen, phosphorus, potash, calcium, magnesium, iron, and manganese compared favorably with that of various crop plants such as alfalfa, clover, timothy, red top, corn stalks, and wheat straw. Weeds feed heavily and utilize fertility which would otherwise be available for competing crop plants. Concerning their effect on the nitrate contents of soils, the upper three feet, where weeds were permitted to grow, contained 81.6 pounds of nitrates, while a comparable area with a three-inch mulch contained 413.3 pounds of nitrates per acre.

Practically every state has laws regulating the sale of crop seeds and limiting the sale of those containing mixtures of certain undesirable weed seeds. Aside from the reduced yields of the crop variety as a result of weed competition, the presence of the weed seeds greatly lowers the market value of the crop seed and thus imposes a double tax on the farmers.

Weeds are not only a problem of the farmer, rancher, and forester, but of highways, public utilities, rights-of-ways, railroads, power and communication line systems—and the home owner and backyard gardener.

Plants commonly classed as weeds are not always harmful, however. They may do much good in providing cover to prevent erosion and through their growth may increase the available fertility of soil; tobacco, for instance, following certain species of weeds, is superior to that produced on bare fallow.

The Organization of Weed Control

WEED control is developing as a separate scientific discipline and not as a branch of any single science such as has handicapped many branches of agriculture in the past. It is a combination of agronomy, horticulture, forestry, chemistry, agricultural engineering, and public health. It draws heavily on the supporting sciences including chemistry, physics, botany, ecology, physiology, mathematics, engineering and others.

Shaw (1955) points out that, "one of the most unique aspects of the science of weed control is the requirement for cooperative effort. The organization of weed work in the United States strongly reflects this basic need. Essentially, weed work involves a combination of federal, state, industrial and independent agencies participating in the research, regulatory, develpment, extension, and teaching phases of weed control.

"In the United States Department of Agriculture, excepting the Forest Service, the responsibility for weed research and regulatory aspects is centered in the Agricultural Research Service while the extension phase is the responsibility of the Federal Agricultural Extension Service. The weed research in the Department is conducted in or coordinated by the Weed Investigations Section, Field Crops Research Branch, Crops Research, Agricultural Research Service.

"The research program of the Weed Investigations Section includes studies on cultural, ecological, chemical, mechanical, and biological methods of controlling weeds. These methods of weed control are incorporated in four broad general projects including: (1) research on the evaluation of chemicals for their herbicidal properties, including studies on the factors affecting the efficiency of chemicals as herbicides, (2) research on the physiology and ecology of weeds, (3) research on weed control in cultivated crops, including field and horticultural crops on non-irrigated and irrigated lands and (4) research on weed control in pasture and rangelands and non-cultivated areas. The head of the Section and project leaders are responsible for developing the research program to be conducted in these four general projects. The research program is coordinated in the field by four regional research coordinators with regional headquarters. . .. At present the research program of the Weed Investigations Section involves cooperative investigations with 23 States and studies at eight locations that are federally controlled. In addition to the investigations conducted in cooperation with State Weed Research programs, the Section research program involves cooperative herbicide evaluation studies with 39 chemical companies engaged in screening and herbicide evaluation studies."

The research, extension, and regulatory phases of the field of weed control are coordinated through the four regional weed conferences which meet annually. These include: The Southern Weed Conference, The Northeastern Weed Control Conference, the North Central Weed Control Conference and The Western Weed Control Conference. Personnel attending the conferences present the most recent advances in the field of weed control and formulate weed control recommendations on a regional basis. The four regional conferences have formed The Association of Regional Weed Control

Conferences (ARWCC) which represents the interests of the regional conferences on matters of national interest. For example, the "Weeds" Journal and the First National Weed Conference were sponsored by ARWCC. Recently weed personnel have formed a national weed society, The Weed Society of America.

The U. S. Forest Service has recently entered the field of tree, weed and brush research and control. A big, almost untouched field in forestry is waiting for development by owners, silviculturalists, and forest managers. The use of concentrated silvicidal sprays appears to be the brightest spot on the horizon in forest management.

Recent Advances In Chemical Weed Control Research

MANY important advances have been made recently in cultural, mechanical, and biological methods of controlling weeds. Cultural practices are and always will remain important weed control techniques. Numerous weed research investigations and farm practice have shown that good clean seed is a sound starting point for any weed control program. Thorough seedbed preparation, followed by clean, efficient, shallow, timely cultivation, has an extremely important place in weed control. There are no substitutes for proper fertilization and management of adapted species, varieties or hybrids of crop plants. Nevertheless the progress in the field of chemical weed control during the past ten years has been almost fantastic. Within this brief period, many new chemicals and new weed control techniques have been developed. Three of the most important developments in weed control in the past decade were the discovery of the herbicidal properties of the phenoxy compounds, the introduction of pre-emergence weed control and the *development of the technique of low gallonage application.* (See Chapters III and IV.)

These discoveries have had a profound effect on the entire scope of and accomplishments in the field of weed control. For this reason I would like to discuss briefly the scope of chemical weed control research in the United States and some of the accomplishments that have resulted from these investigations.

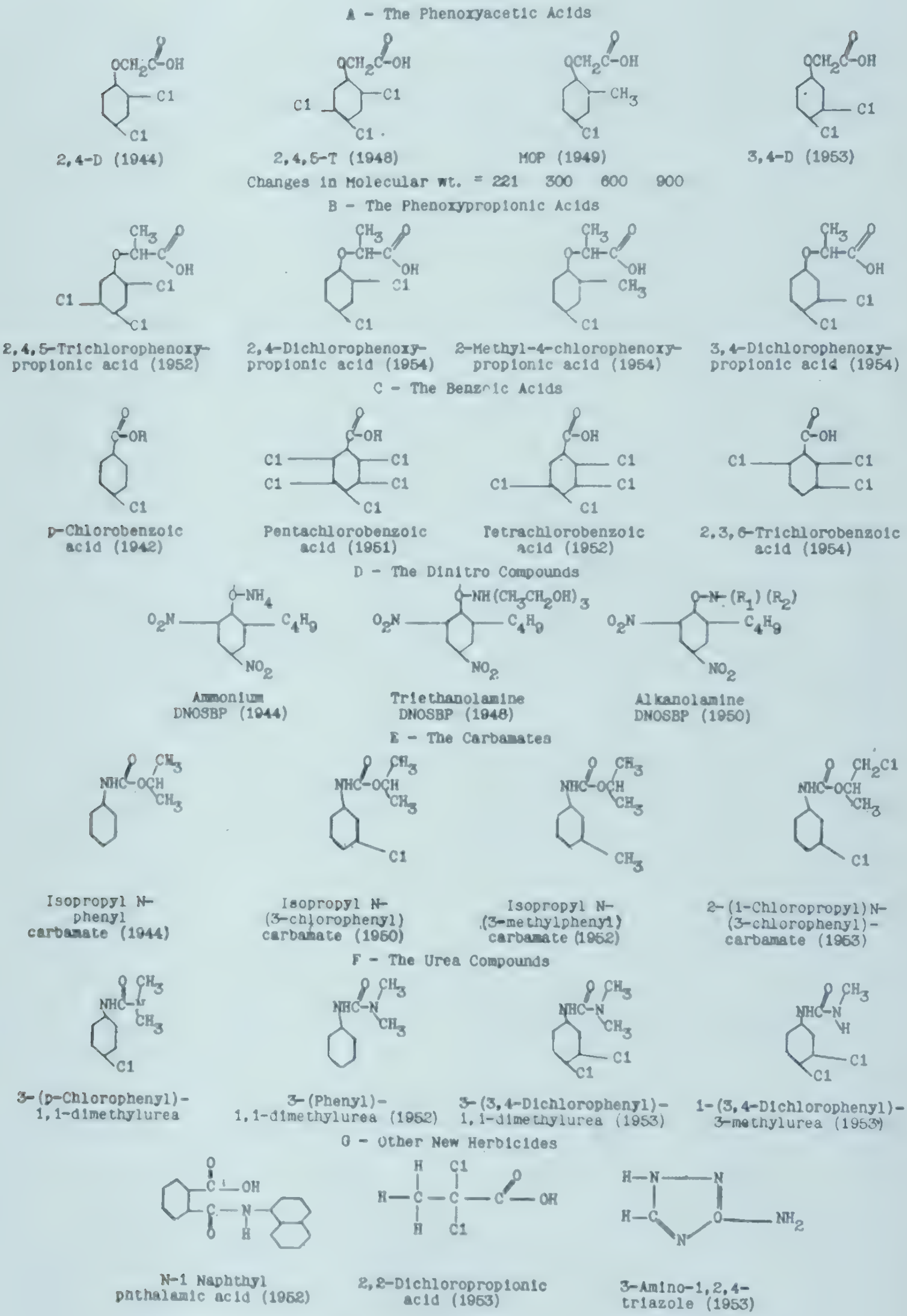
Screening and Evaluating Studies

SHAW (1955) states that "The screening, evaluation, and development of new agricultural chemicals as herbicides in the past ten years in the United States has occurred at a rate which has exceeded the imagination. Most of the credit for these developments is due to an efficient forward thinking Chemical Industry working in close cooperation with Federal and State research agencies. Not all the discoveries have been made by industrial scientists, but regardless of where the activity of such products is discovered it eventually becomes the responsibility of industry to manufacture them.

"Quite aside from empirical screening are herbicide evaluation studies which involve fundamental, systematic studies of families of compounds or closely related compounds to determine the relation between molecular structure and herbicidal activity, including studies of the properties of chemicals and other factors affecting herbicidal efficiency. In the United States, scientists have looked largely to the chemical industry as a source of these compounds. The good relations, mutual respect, and confidence that have developed has provided the primary impetus in this rapid development of herbicides."

Screening and evaluation should take into account many items such as cost, selectivity, dosage, optimum concentrations, optimum gallonage, timing, number of applications, pounds per acre, solubility and type of possible formulations, compatibility, safety features and hazards, kind of toxic action—whether by contact, root absorption, foliage absorption, translocating systemic action or not, hormone or non-hormone type, and length of residual effect; and the optimum drop size and suitability for various kinds of equipment, both ground and aerial. It must also be determined whether the chemicals are suitable for treatment in soil application, pre-emergence, post-emergence, basal (dormant and summer), and combination treatments.

One of the most important of these items is the suitability of the chemicals and formulations for low gallonage and concentrate application. Most any chemical spray that comes into large scale use must be suited for concentrated spray application. The indications are that in the future practically all herbicide sprays will be made in the form of concentrated spray, using less than 16 gallons per acre. In concentrate application the number of pounds actual toxicant that can be incorporated in a gallon of mixture and the number of gallons required per acre are very important items, especially in aerial application where the cost of treatment is roughly proportional to weight of material applied per acre. Solutions and emulsions are definitely preferred over wettable powders because of several reasons, including the latter's tendency to clog nozzles, its agitation requirements, abrasiveness, etc. At this point the reader



A - The Phenoxyacetic Acids

2,4-D (1944)
2,4,5-T (1948)
MOP (1949)
3,4-D (1953)

Changes in Molecular wt. = 221 300 600 900

B - The Phenoxypropionic Acids

2,4,5-Trichlorophenoxypropionic acid (1952)
2,4-Dichlorophenoxypropionic acid (1954)
2-Methyl-4-chlorophenoxypropionic acid (1954)
3,4-Dichlorophenoxypropionic acid (1954)

C - The Benzoic Acids

p-Chlorobenzoic acid (1942)
Pentachlorobenzoic acid (1951)
Tetrachlorobenzoic acid (1952)
2,3,6-Trichlorobenzoic acid (1954)

D - The Dinitro Compounds

Ammonium DNOSBP (1944)
Triethanolamine DNOSBP (1948)
Alkanolamine DNOSBP (1950)

E - The Carbamates

Isopropyl N-phenyl carbamate (1944)
Isopropyl N-(3-chlorophenyl) carbamate (1950)
Isopropyl N-(3-methylphenyl) carbamate (1952)
2-(1-Chloropropyl)N-(3-chlorophenyl)-carbamate (1953)

F - The Urea Compounds

3-(p-Chlorophenyl)-1,1-dimethylurea
3-(Phenyl)-1,1-dimethylurea (1952)
3-(3,4-Dichlorophenyl)-1,1-dimethylurea (1953)
1-(3,4-Dichlorophenyl)-3-methylurea (1953)

G - Other New Herbicides

N-1 Naphthyl phthalamic acid (1952)
2,2-Dichloropropionic acid (1953)
3-Amino-1,2,4-triazole (1953)

Figure 147. Trends in the development of herbicides.

Courtesy of W. C. Shaw, USDA, ARS.

is urged to review the preceding chapters on equipment and spray formulation methods.

Shaw (1955) points out that "A potent stimulus to herbicide evaluation and development research has resulted from studies designed to develop equipment and techniques for the application and evaluation of chemicals as herbicides. Much progress has been made in this field and much additional work is needed."

Chemicals

IN a further report, Shaw (1955) says, "We are tending to use more herbicides and to use specific herbicides for the control of specific weeds in specific crops. The present demands of a new herbicide necessitate that careful consideration be given to all factors affecting the specificity and selectivity of a particular chemical. The rate of development and some of the trends in the development of herbicides are presented in Figure 147.

The Phenoxyacetic and Phenoxypropionic Acids

"The use of these chemicals for the control of broadleaved weeds in tolerant grasses and other plant species as post-emergence sprays and for the control of annual grasses and weeds in tolerant crops as pre-emergence sprays has increased at a rapid rate. Recent studies have shown that the propionic acids may add a great deal of selectivity and specificity to that already possible with the phenoxyacetic acids. In addition to 2,4-D, 2,4,5-T, MCP and 3,4-D, the 4-chlorophenoxy and 2,5-dichlorophenoxy acetic and propionic acid derivatives also show promise as herbicides. (Figure 147, A and B)."

2,4-D is a selective herbicide killing broadleaved weeds and not materially affecting grasses. It is also effective for control of some woody plants. It is obtainable in various forms as amine salts and as high volatile esters and low volatile esters. The amine salts are practically non-volatile and are the safest 2,4-D formulations from the standpoint of volatility. They are not generally as effective as the esters, particularly when growing conditions are not favorable for rapid plant growth. High volatile esters include methyl, ethyl, butyl, propyl, isopropyl and amyl (pentyl) series. They were more widely used before the advent of lower volatile formulations. Low volatile esters are in widespread use in lawn, pasture, and roadside spray programs. Amine salts are applied in water only. Esters can be applied with either water or oil. Both 2,4-D and 2,4,5-T are ideally suited for low gallonage concentrate application from the ground and from the air. They may be applied in an oil solution or as an emulsion. On crops, from ¼ to 2 pounds of 2,4-D acid is used per acre but for foliar applications to brush and hardwoods, dosages of 1to 4 pounds of 2,4,5-T acid are applied. Avoid drift.

2,4,5-T is used for broadleaved, woody vegetation along roadsides, rights-of-way, brush areas, and in forest management. White pine and many conifers are not killed by moderate 2,4,5-T dosages, whereas most deciduous trees are very susceptible. Therefore, at this time 2,4,5-T is the most important chemical for the forester to apply for releasing conifers trying to compete with brush and hardwoods. It is also effective on clovers.

Also, 2,4,5-T and mixtures with 2,4-D has special merit for application at any time of year as a basal or stump treatment, when used in oil at a 2 to 4 per cent acid concentration, using knapsack sprayers and small power equipment with light hoses.

Erbon, 2(2,4,5-Trichlorophenoxy) ethyl-2, 2-dichloropropionate, like CMU is a non-selective herbicide used as a soil sterilant where complete devegetation is desired, such as around fence posts, guard rails, highway markers, etc. It is effective for both weeds and grasses but appears less effective on hardwoods. It should be applied in sufficient water for good coverage of vegetation and exposed areas of soil, preferably in Spring after vegetative growth is well started.

Amino triazole (3-amino-1, 2, 4-triazole) is the most effective material thus far for poison ivy, poison oak, Canada thistle, and certain other troublesome perennial species. It is also promising for quack grass, nut grass, and cattails. Otherwise, it does not control as many different species as either 2,4-D or 2,4,5-T. Apply to foliage in water solution at sufficient dosages and avoid drift beyond treated areas. Most effective time to treat is when the foliage is fully formed and weed plants are in active stage of growth.

Silvex—2 (2,4,5-Trichlorophenoxy) propionic acid, known as "Kuron," "Propon," or "2,4,5-T Propionic" is especially effective in controlling members of the oak group of woody plants as a foliage spray after the latter is fully developed. It may be used in oil or in an oil-water emulsion. It is effective against fewer species than 2,4-D or 2,4,5-T.

Dalapon, 2,2-dichloropropionic acid, is particularly effective in controlling cattail in ditches, and for troublesome perennial grasses such as Bermuda grass and Johnson grass, and for grass control on old sods. Dalapon can be combined with 2,4-D or 2,4,5-T for the control of both weeds and grass.

TCA at 5 to 10 pounds per acre is effective against many annual grass seedlings without causing serious injury to sugar beets, flax, and alfalfa.

Endothal is effective on clovers.

Leaf Penetration of 2,4-D

Figure 148 is a graphic presentation of what happens when a leaf is sprayed with 2,4-D. Explanation of the figure is as follows, beginning with the cut on left side:

A. One droplet of 2,4-D has hit this spot on the leaf.

B. Within a few hours the outer "skin" cells of the leaf are breaking down.

C. Rapidly, the 2,4-D penetrates to the inner cells.

D. Next, it reaches the leaf's inner veins which carry it into the plant system.

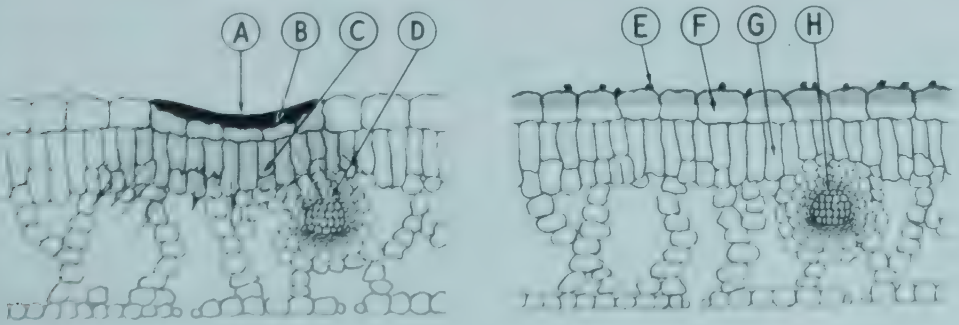
Legend to cut on the right side: This leaf was sprayed with a salt form of 2,4-D:

E. As the spray solution evaporates, dry particles of the salts remain on the leaf surface. Rain can wash them off.

F. The salt-type 2,4-D has only penetrated the outer layer of "skin" cells.

G. Moisture or leaf acid is required before these salts may dissolve and enter the leaf tissue. Hence, they act more slowly.

Figure 148. Leaf Penetration of 2,4-D.



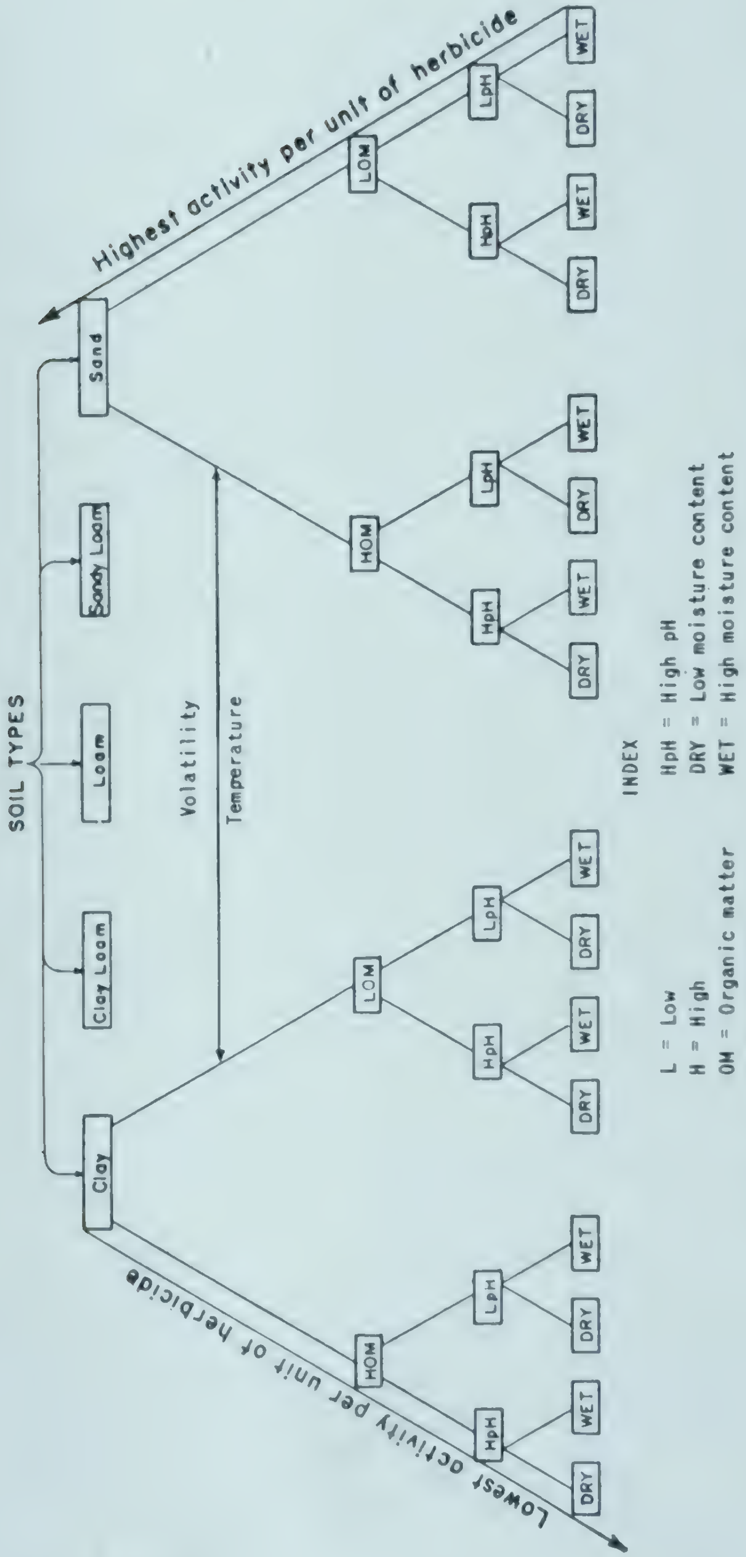

SOIL TYPES
Clay
Clay Loam
Loam
Sandy Loam
Sand
Volatility
Temperature
Highest activity per unit of herbicide
Lowest activity per unit of herbicide
HOM
LOM
HpH
LpH
DRY
WET
INDEX
L = Low
H = High
OM = Organic matter
LpH = Low pH
HpH = High pH
DRY = Low moisture content
WET = High moisture content

Figure 149. The effect of some soil properties on the activity of herbicides

Courtsy of W. C. Shaw, 1955.

The Benzoic Acids

Shaw (1955) notes that "These compounds have been studied intensively for their growth regulating properties since 1942. The herbicidal properties and persistence of these compounds in soils have been of considerable interest to weed research workers interested in pre-emergence weed control. In recent preliminary studies, 2,3-6-trichlorobenzoic acid has shown promise as a residual pre-emergence herbicide for weed control in corn *(Zea mays)*, and sorghum *(Sorghum vulgare)*. These compounds appear to be more persistent and less likely to leach in soils than are the phenoxy type compounds. For these and other reasons, this family of compounds is expected to contribute greatly to the versatility of the pre-emergence chemical attack on weeds (Figure 147C)

The Substituted Phenols

"The dinitro alkyl phenols and chloro substituted phenols have been used widely as contact selective and non-selective post-emergence herbicides. More recently they have been developed as pre-emergence herbicides for use in a number of large seeded crops including cotton, peanuts and soybeans. Many studies have shown that these compounds are essentially contact, non-translocated herbicides, but very little additional information was available on the basic effects of these chemicals on plant growth until recently. As illustrated in Figure 147, emphasis has been placed on selectivity, specificity, lower phytotoxicity, and lower vapour activity in the successive development of the ammonium, triethanolamine, and alkanolamine salts of dinitro ortho secondary butyl phenol. More fundamental research is needed to understand more fully the effects of this group of chemicals on plant growth.

The Carbamates

"The substituted N-phenyl carbamates have exhibited a high degree of selectivity and specificity as herbicides. This high degree of specificity and selectivity has led to their wide scale use as post-emergence sprays for the control of annual grasses in legume crops, and more recently as pre-emergence treatments for weed control in cotton, vegetables, and other crops. Recent studies indicate that isopropyl N-(3-methylphenyl) carbamate, 2-(1-chloropropyl) N-(3-chlorophenyl) carbamate (Figure 147) and other derivatives in addition to isopropyl N-phenylcarbamate (IPC) and isopropyl (N-

(3-chlorophenyl) carbamate (CIPC) possess important herbicidal properties. As indicated in Figure 147 the trend in the development of the carbamates has been to develop low volatile derivatives with a high degree of selectivity and specificity."

"CDEC (2-chloroallyl diethyldithiocarbamate) is a new very promising material for controlling annual grasses at 2.5 to 6 pounds per acre and is especially useful for corn.

The Substituted Ureas

"These compounds, represented at present by 3-(p-chlorophenyl)-1, 1-dimethylurea, 3-(phenyl)-1, 1-dimethylurea, 3-(3,4-dichloro phenyl)-1, 1-dimethylurea, and 1-(3,4-dichlorophenyl)-3-methylurea are among the most promising new pre-emergence herbicides and soil sterilants that have been introduced in the field of weed control. The urea herbicides are the first group of organic chemicals having sufficient stability and residual effect in the soil to be used as soil sterilants. As a group these compounds are valuable new tools for the attack on weeds on non-agricultural lands. However, much more must be learned about their fate in the soil before they can be recommended widely, especially as pre-emergence herbicides on crop land. (Figure 147).

Other New Herbicides

"Some of these include N-1, naphthyl phthalamic acid, Dalapon, 2,2-dichloropropionic acid, 3-amino-1, 2,4-triazole; and there are others. The phthalamic acids have shown promise as pre-emergence herbicides for weed control in cucurbits and other crops. The new herbicides 2,2-dichloropropionic acid is a methylated derivative closely related to trichloroacetic acid. However, unlike trichloroacetic acid it appears to be readily translocated downward when applied to the leaves of certain grasses. It also has shown promise as a pre-emergence herbicide in a number of crops. Another new herbicide, 3-amino, 1,2,4-triazole is translocated in certain monocots and grasses, and inhibits chlorophyll production in a number of species. This compound shows promise as a post-emergence spray for the control of grasses, as a pre emergence spray for the control of weeds in several crops, and as a fortifying agent in general weed killing sprays on industrial areas. A versatile compound, it is also being used for cotton defoliation."

There are at least 25 other very promising new and relatively new materials that should be mentioned including CDEC (a carbamate), two acetamides—CDAA and CDEA, TBA (HC-1281-S) sodium salts of trichlorobenzoic acid, 2,4-D acetamide pre-emergence material for corn, Diuron (dichlorophenyl 1-dimethyl urea 80%), CMU: (3-(*P*-Chlorophenyl)-1-1-dimethyl urea), Alanap (wettable powder and liquid forms), Maleic hydrazide (MH), and others.

CDEC, CDAA, and CDEA are particularly promising for annual weedy grasses at rates ranging from 2 to 6 pounds per acre. CMU and DCMU (Diuron) are non-selective soil sterilants at rates ranging from 20 to 80 pounds per acre. At rates of ½ to 2 pounds per acre they may be used selectively to control weeds and grasses without damaging certain crops under specified methods of application and timing. When using powder formulations agitation of the spray suspensions is necessary to prevent settling out of the chemicals.

Alanap (sodium-N-1-naphthyl phthalamate) is a useful pre-emergence material for application to the surface of the soil before or after planting trees or shrubs for control of annual grasses and weeds. For crab grass control on lawns and turf it is usually used at the rate of about six pounds per acre. The first treatment is made in the spring just before the seeds start germinating. This application is then followed by one or two other applications at 2 to 3 week intervals.

Maleic hydrazide is a growth regulator particularly useful for inhibiting the growth of grass to reduce frequency of mowing lawns and highway areas. It is usually applied in water with either hydraulic sprayers or concentrate sprayers. The applications should be started in the spring when green grass is two to three inches high. The length of time that grass is inhibited is directly proportionate to the area of foliage and the pounds per acre used. Too high dosage may cause a temporary browning of the grass.

Old Herbicides and Silvicides

AMMATE (ammonium sulfamate) is effective for the control of many brush or woody species, including species resistant to hormone-type herbicides. It has both a contact and a residual translocated herbicidal action, and is safe to use near crops where volatility of hormones would be hazardous. Ammate is not generally recommended for elimination of perennial or annual herbaceous weeds. It is applied in a solution of ¾ to one pound of Ammate per gallon of water, using 100 to 400 gallons of mixture per acre. The foliar spray is most effective when put on after the leaves and needles are fully developed. This chemical is rough on metallic equipment, especially copper and brass. Its use is limited by the fact that it is one of several herbicides that are not well adapted for concentrated spray application. However, an emulsifiable form containing six pounds of Ammate per gallon was developed in 1957 for application in concentrated spray form at 10 to 20 gallons per acre. A crystal form is available for applying in cut notches in freshly cut stumps.

Sodium Arsenite is a water soluble, sprayable, highly poisonous, and highly phytotoxic non-selective herbicide and silvicide. It is beginning to lose ground, partly because of its poisonous nature.

Sodium Chlorate and boron (borates) are non-selective herbicides for soil sterilant uses where complete kill is desired. They are effective for control of most weeds and grasses at higher application rates. Sodium chlorate presents a fire hazard and should be used carefully. It can be applied throughout the year, including summer, fall, or winter.

Oils

Various petroleum fractions have long been used as herbicides, and contrary to general opinion are, directly or indirectly, playing a greater part in modern development in weed control than ever before.

Broad refinery cuts of petroleum distillation are used widely as contact, non-selective herbicides by railroads on roadbeds and sidings. Special cuts of phytotoxic oils are widely employed for control of herbaceous weed growth on canal and ditch banks, along highways and in orchards in the Southwest. Highly refined aromatic fractions are employed for control of submerged aquatic weeds in irrigation systems, and lately for selective control of weeds in cotton.

Petroleum is one of the basic materials from which our highly efficient organic herbicides such as 2,4-D, 2,4,5-T, CIPC, and dinitros, are derived. In addition, fuel oil (No. 1 or No. 2) is widely used as a carrier for esters of 2,4-D and 2,4,5-T in concentrate application by aircraft on cereal grains, forests, and for control of woody species on range land in the western and southwestern range areas.

In considering the total picture of use of herbicides in weed control today, a conservative estimate of annual consumption of 25 million gallons of petroleum products is involved.

Waste Cuts. With the growing demand for petroleum products and improvement in the refining processes, waste or refined cuts are becoming less availabe as herbicides. These cheap waste cuts were formerly widely used by railroads in track and siding weed control. They are now being replaced by special weed oils, generally high boiling fractions that are potent contact herbicides.

These special fractions are marketed by certain refineries for weed control on public utilities, farms, and ranches. With proper emulsifiers they can be mixed with water at any ratio desired for quick contact killing of young foliage of annual weeds. Utility of these materials is limited by relative cost and availability, and by availability of suitable equipment for applying them. Usually 5 to 15 gallons of actual oil per acre are required.

Stoddard solvents, petroleum fractions commonly used as dry cleaning fluids, and PD544B, UD544C, Velsicol AR 60, are being widely used in specialized weed control. They are highly selective in eliminating seedling broadleaved and grass weeds in carrots, parsnips, celery, and parsley, as well as in nursery seedlings of conifers.

Stahler (1953) shows that: "These vegetable and nursery crops are highly tolerant of the action of these distillates which are potent herbicides on many of the common weeds associated with their production. Oily residual flavor of the vegetable crop is a hazard in use of Stoddard solvents. That can be avoided by using these only when crops and weeds are in early stages of development. Repeated applications may be needed to keep the pest growth in check throughout the season, depending on conditions."

Weed Control in Horticultural Crops

THE practices outlined below are only an indication of the practices developed and the research advances that have been made and should not be interpreted as recommendations for any particular region or section in the United States. Further testing will show, too, that the herbicides can be used at higher concentrations and in lower volumes per acre, thereby reducing application costs.

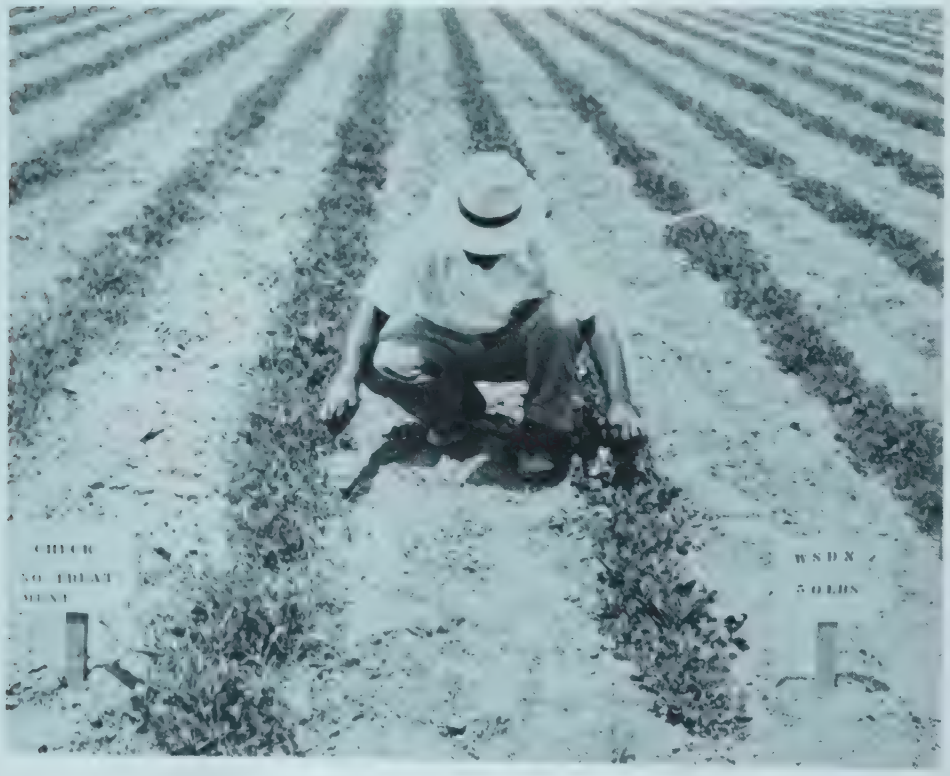
Asparagus. The most common practice is to disc asparagus beds to loosen the soil, destroy the weeds, and to remove the old ferns. After discing and prior to spear emergence, 2,4-D, SES, TCA, DNOSBP, CIPC, CMU, or N-1 naphthyl phthalamic acid or combinations of these compounds as pre-emergence treatments may be used to control broadleaved weeds and grasses. The compound or combinations of compounds and the rates to use will depend on the weed problem, soil type and other factors.

After harvest, disc the beds and apply 2,4-D, SES, DNOSBP, CIPC, CMU, or N-1 naphthyl phthalamic acid or combinations of the compounds as pre-emergence treatments.

Beans. The same treatments are suggested as for soybeans. In some areas PCP is used also as a pre-emergence herbicide for weed control in snapbeans and lima beans.

Beets. TCA, PCP, or IPC and combinations of these chemicals or these compounds in combination with endothal are being used as pre-emergence treatments. TCA is the most widely used herbicide in red beets or sugar beets. The combination treatments are usually used in localized areas to control wild oats *(Avena fatua)* and several broadleaved species not controlled by TCA. The same chemical combinations are being used in sugar beets.

Figure 150. Weed control in peanuts.



CABBAGE, CAULIFLOWER, COLLARDS, KALE, RAPE, BROCCOLI, TURNIP, MUSTARD, LETTUCE, AND IN GENERAL, VEGETABLES BELONGING TO THE GENUS BRASSICA. When these crops are direct seeded, TCA may be used as pre-emergence treatment to control annual grasses and certain broadleaved weeds. Recent studies have shown also that CIPC may be used effectively in several areas in the United States as a pre-emergence treatment for weed control in these crops.

CARROTS, CELERY, DILL, PARSNIPS, AND PARSLEY. Small annual weeds may be controlled on muck and upland soils with applications of undiluted Stoddard solvent at 80 to 100 gallons per acre. The treatment should be made when the weeds are two to three inches tall and before the tap roots of carrots and parsnips are more than ¼ inch in diameter. Maximum effectiveness may be obtained when air movements are down and the relative humidity is high.

CANTALOUPES, CUCUMBERS, MUSKMELLONS AND WATERMELONS. Pre-emergence treatments of N-1 naphthyl phthalamic acid have proven successful in controlling annual broadleaved weeds and grasses in these vine crops. Certain varieties of pumpkins and squash are not tolerant to this treatment and varietal responses should be known prior to large scale use.

ONIONS. For pre-emergence weed control, stoddard solvent at 40 to 80 gallons per acre, a 3 to 5 per cent solution of sulphuric acid at 100 gallons of water per acre, or CIPC at 2 to 8 pounds per acre may be used. The chemical and rate of application will be determined by the soil type and the weeds present .

For post-emergence weed control after the first true leaf of onions is at least two to three inches long (loop stage), a post-emergence spray of 2 to 3 per cent sulfuric acid at 100 gallons per acre or potassium cyanate at 12 to 16 pounds in 50 to 100 gallons of water is suggested.

For weed control in onions in the five leaf stage and after the last cultivation when the onions are being or have been "laid by" and are bulbing, basal directed post-emergence treatments applied so as to avoid hitting the tops of the onion plants are suggested. A 3 to 4 per cent sulfuric acid solution in water at 100 gallons per acre, potassium cyanate at 16 to 20 pounds, CIPC at 2 to 8 pounds, DNOSBP at 1 to 2 pounds or CMU at two pounds in 50 to 100 gallons of water per acre is suggested. The chemical and rate of application to use will be determined by the weeds present, the soil type, and the stage of growth of the onions and the weeds.

Potatoes. For pre-emergence weed control following blind cultivation prior to the emergence of the potatoes, DNOSBP at 3 to 6 pounds, PCP at 10 to 20 pounds, TCA at 8 to 10 pounds, 2,4-D at 1 to 2 pounds and CMU at 1 to 2 pounds in 20 to 50 gallons of water per acre may be used for the control of annual weeds. For the control of weeds following the last cultivation, SES at three pounds in 40 gallons of water per acre should be applied immediately following the last cultivation.

Brambles. Weeds that grow in brambles grown in the hedge or linear system are difficult to control with mechanical implements. Suitable mulches will aid in reducing the weed problems but mulching costs are usually high. The bramble crops are tolerant to a number of herbicides. For the control of weeds in early spring, SES at three pounds, 2,4-D at ½ to 1 pound, or DNOSBP at 2 to 4 pounds in 20 to 40 gallons of water per acre should be applied prior to emergence of the weeds or new canes. The second application should be delayed until the new canes are tall enough to permit a directed basal application so as to avoid getting the spray on the cane tips. SES must always be applied to the soil before weeds emerge or if weeds have emerged the seedbed must be clean cultivated before treatment. All other basal directed sprays should be applied when the weeds are small.

Grapes. For the control of weeds beneath the trellis, treatments with oil water emulsions of DNOSBP, PCP, CIPC and mixtures of CIPC and DNOSBP have proven effective. A mixture consisting of six pounds of CIPC plus two pounds of oil soluble DNOSBP in an oil (20 gals.)-water (80 gals.) emulsion at 100 gallons per acre has given excellent control of emerged grasses and broadleaved weeds. The contact action of DNOSBP kills the emerged annuals and the CIPC provides residual pre-emergence weed control. The spray treatment should be directed so as to avoid the grape trunks as much as possible. Do *not* use 2,4-D in the vicinity of grapes or cotton.

Strawberries. For weed control on a full year basis, pre-planting treatments of DNOSBP at 8 to 10 pounds or CIPC at 4 to 8 pounds per acre followed by post-planting treatments of SES as needed (30 day intervals) will give good control of weeds in strawberries from planting until fall dormancy. Cultivation should precede each SES treatment until runner production limits cultivation. For fall and winter weed control when strawberries are dormant, DNOSBP at 1 to 2 pounds and CIPC at 2 to 4 pounds in 40 gallons of water will give excellent control of winter annual broadleaved weeds and grasses. For the control of broadleaved weeds, 2,4-D may be used as a selective foliage treatment at the rate of ½ to 1 pound per acre during the period from 2 to 4 weeks after setting until fruit bud differentiation begins.

NURSERY STOCK. Methyl bromide and other soil fumigants may be used to control weeds in transplant beds and seedling beds. Stoddard solvent or equivalent non-fortified aromatic oils and aromatic oils fortified with PCP or DNOSBP may be used for the control of seedling weeds in coniferous seedling and transplant beds, and for weed control in coniferous transplants and deciduous stock in rows respectively. The sprays should be basal directed so that application to the stems of nursery stock is avoided as much as possible. CIPC, Dalapon, and SES are also being used in a veriety of ways for weed control in nurseries.

Weed Control in Field Crops

THE state experiment stations and extension services, and each of the four regional sections of the Weed Society of America has drawn up rather complete recommendations for field crops, particularly corn, sorghum, soybeans, peanuts, snapbeans, and lima beans; wheat, oats, barley, alfalfa, Ladino clover, white clover, flax, tall fescue, orchard grass, blue grass, and other perennial grasses.

Growers should write the above agencies and the United States Department of Agriculture for latest recommendations for their particular crop, soil, and locality.

The information on the next few pages for corn, sorghum, rice, cotton, soybeans, and pastures relates more specifically to Southern areas. However, it has a general application to weed and grass control in other areas as well. It is condensed from the Mississippi Agricultural Experiment Station Weed Control Recommendations (1955).

CORN. The weed problems in southern corn may be broadly classified into early-season and late-season ones. The former is usually due to crabgrass, *Brachiaria spp.*, and certain other small-seeded weeds, whereas the late-season weeds, principally morning-glory and cocklebur may develop after the last cultivation and cause lodging and lower mechanical picker efficiency. Two kinds of chemical treatments are recommended for the above problems.

Pre-Emergence Treatment: On farms where annual weeds present an early season problem the use of 4,6-dinitro-o-secondary butyl phenol (DNBP), and certain salts of this material, is suggested for pre-emergence application. The herbicide is applied as a band treatment in the same operation with planting in exactly the same manner as recommended for CIPC on cotton. Rates of application should be 1½ to 2 pounds per acre on a 12-inch basis. The material is not recommended for light sandy or heavy clay soils. The dinitros do not present as serious a drift hazard as 2,4-D but they are poisonous to warm-blooded animals and therefore instructions on the manufacturer's label should be read and strictly observed.

Post-Emergence Treatment: Broadleaved weeds such as ragweed, cocklebur and morning-glory may be readily controlled in corn by spray treatment with amine 2,4-D. If the weeds occur before the corn is 12 inches tall an overall broadcast spray may be made at the rate of ⅓ to ½ pound per acre using 10 to 20 gallons of water. This overall treatment, however, may cause some stalk brittleness and injury to the corn brace roots.

Where the broadleaf weeds are present at and after lay-by, sprays of amine 2,4-D should be applied to give good coverage of the tops of the weeds. Insofar as possible avoid spraying the corn leaves and stalks except for a few inches at the ground level. Drop nozzles can be employed, using 2 or 3 nozzles per middle to give good spray coverage of the weeds in the middles and the drill. An application rate of ½ pound per acre on a broadcast basis is recommended. If weeds occur in the drill only the amounts of 2,4-D and water are reduced in proportion to the area actually sprayed.

The post-emergence treatments may be made on corn growing on any soil type but grassy weeds are not controlled by the 2,4-D. The cost of controlling tall growing broadleaf weeds in corn with 2,4-D is frequently more than off-set by improved picker efficiency alone. Corn should not be treated with 2,4-D at the silking and tasselling stage but the directional sprays can be applied safely at all other stages.

RICE. Coffee-weed, also known as indigo and coffee-bean, can be controlled in rice fields with 2,4-D 2,4,5-T, and MCP. These materials should not be applied when it is windy nor when a breeze is blowing toward a nearby field where cotton or other sensitive crops are being grown. Soybeans, sweetpotatoes, and many of the common vegetables are sensitive, but cotton is particularly sensitive to these materials. Field research over a period of several years has indicated that 2,4,5-T and MCP are not as toxic to cotton as 2,4-D at equivalent rates. This should not be taken as meaning that these herbicides will not injure cotton, but rather that injury to cotton from drift of 2,4,5-T and MCP is usually not as severe as that caused by 2,4-D.

Certain esters of these chemicals are volatile and vapors will move for great distances. Several commercial concerns now formulate *LOW VOLATILE ESTERS* which will give the desired weed control without a vapor hazard. Because of the risk involved in using the volatile esters of these chemicals, the following recommendation applies only to spray applications of the *AMINE* and *LOW VOLATILE ESTER* formulations.

Time to Spray. Rice seedlings are sensitive to 2,4-D, but this sensitivity decreases with age up to boot stage. If treated at or after the boot stage, a serious reduction in yield may result.

Rates of Chemicals. 2,4-D and 2,4,5-T: Apply 2,4-D or 2,4,5-T at the rate of ½- to ¾-pound (acid equivalent) per acre in about 10 gallons of water. If weed infestation demands an early application the ½-pound rate may be used as early as three weeks after emergence of the rice. The margin of safety increases with age of the rice and in later treatments the rate should be ¾ pounds per acre.

MCP: Apply MCP at the rate of ¾- to 1-pound (acid equivalent) per acre in about 10 gallons of water. The ¾-pound rate may be used three weeks after emergence of the rice, but one pound should be used in later applications.

The addition of a wetting agent[*] to the chemical solution will increase the effectiveness of the chemicals.

Cotton: *Land Preparation.* A firm settled seedbed is a very important factor in obtaining a stand of cotton. Preparation of a good seedbed is equally important for obtaining best results with post-emergence chemicals and flaming that follow pre-emergence treatment. Fertilizers should be applied in such a way as not to lose moisture from the firm seedbed. The land should be bedded at least two to three weeks in advance of planting to increase the chances of adequate moisture for good germination of the seed. When the seedbed cannot be prepared early, the bed should be firmed with a cultipacker, drag or rollers.

There is no substitute for a good uniform, well-drained seedbed for the best weed control program of any kind. There should be enough loose soil left on the seedbed after the beds have been raked or dragged off to adequately cover the seed. If the planter is equipped with runner wings, it may not be necessary to drag off the row.

---

[*] Good results have been obtained by using Dreft, Tide, etc., at a rate of one tablespoonful per 10 gallons of water.

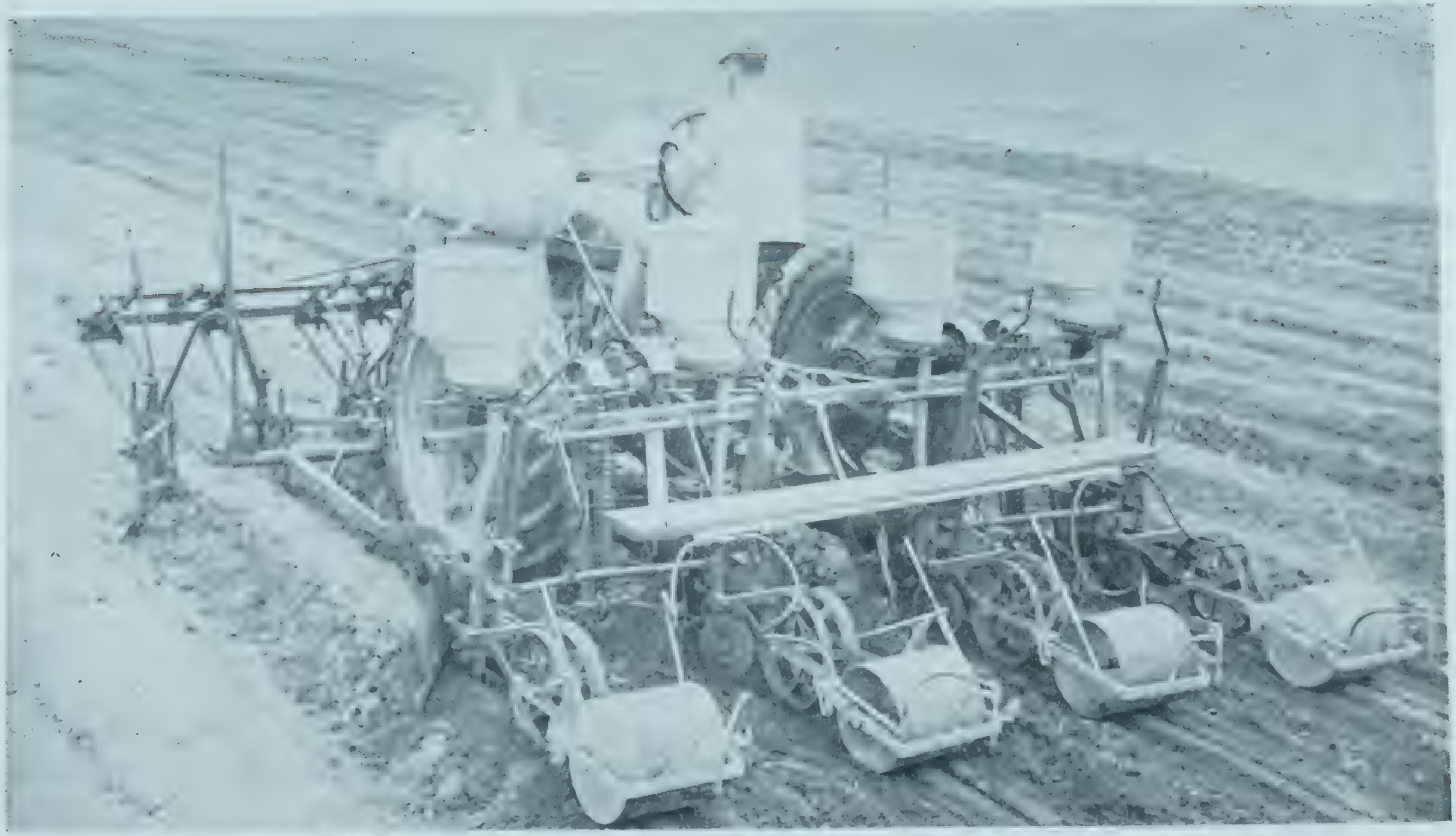


Figure 151. 4-row pre-emergence planting and spraying for weed control in action.

Courtesy Delta Branch Experiment Station, Stoneville, Miss.

Uniformity in height and width of seedbeds is necessary for post-emergence oils and flaming.

All fields should have adequate drainage for the operation of equipment.

Chemical Control of Weeds. The procedure that has given best results in weed control studies over a 6 to 7-year period has been the pre-emergence application of a herbicide followed by post-emergence use of certain herbicidal oils. Many of the chemicals are highly selective and may control undesirable grasses, weeds, and other plants without damaging the crop. Some of them are hormones and some are not; some are soluble in water and other solvents; others have to be applied as powders. Moreover, there is a tremendous range in the optimum dosages and gallonages to be applied. The volume of finished spray to apply may range from one gallon to 40 gallons per acre.

In some pre-emergence treatments before the crop comes up a narrow band is treated on top of the row, in the middle of the row, or the surface of the whole field may be treated. In many cases it will be advisable to combine herbicide application with the planting or cultivation operation. These variations and new uses open up many new uses and methods for applying herbicides and point up the great need for further research, testing, and study of chemicals, plant physiology, equipment, and methods.

Pre-Emergence Treatment. Equipment: Pre-emergence treatments may be made with equipment similar to that used in applying liquid insecticides. Commercial machines are available which apply herbicides satisfactorily. Basically, the equipment consists of a tractor shaft-driven pump, strainers, pressure regulator, gauge, fan-type nozzles, tank for herbicide, and suitable hose for connections. Most 1-, 2-, and 4-row planters can be modified to apply the pre-emergence herbicides correctly.

Planting: Numerous tests for the past three years have shown no advantage in weed control or cotton stands obtained by using a wide roller instead of the regular planter press wheel. However, if post-emergence treatments are to follow pre-emergence applications, a wide flat press wheel will give a better shaped seedbed for the later operations and should be used.

The nozzle should be placed behind the center of the press wheel and positioned at a height to give the band width desired. The cotton seed should be planted at least one-half inch deep and well covered with soil.

Cross-plowing cotton as a measure to obtain weed control has been practiced for a number of years on lands with slopes where erosion has not been a problem. Chemical treatment can be used in combination with cross-plowing to gain weed control. If pre-emergence treatments are to be used, the seed should be drilled at a high rate (60-90 lbs. per acre) rather than hill dropped. The chemical should be applied at the same rate and manner as described below.

Herbicide to Use: Isopropyl N-3-chlorophenyl carbamate (CIPC) is considered the best and safest pre-emergence herbicide to use to date. CIPC is formulated by several companies under different trade names but the active chemical is the same. The chemical is sprayed on the soil behind the planter press wheel at the time of planting. The nozzle is located to the rear of the planter press wheel or extra roller and at the proper position to spray completely a 12 inch band centered on the drill. The pre-emergence application is made in the same operation with planting to insure proper placement of the herbicide. It is almost impossible to get correct placement of the chemical when applied in a separate operation.

Rates of CIPC: On sandy loam soils apply 1 to 2 pounds per acre of the active ingredient in a 12-inch band centered over the row, and on clay loam soils apply 2 to 2½ pounds. The preceding rates of CIPC are recommended for April treatments. Where May treatments are made, increase the rates per acre by ½ pound, i.e., 1½ to 2½ pounds on sandy loam and 2½ to 3 pounds on clay loam soils. In fields consisting of mixed soils the rate should be selected in accordance with the major soil type in the field. If in doubt about the rate for the soil type, use the lower rate. CIPC is not recommended for use on extremely sandy soils or heavy clay soils such as Buckshot, Houston, etc. Should perennial weeds and annual grasses occur in the same field and some hand hoeing is known to be required to control the perennials, it is suggested that CIPC be used only at the lower rate with a view to reducing hand labor requirement and providing some insurance against prolonged rainy periods.

Ureas: Two substituted ureas, CMU*, 3- (p-chlorophenyl) 1, 1-dimethyl urea and 3- (3,4-dichlorophenyl) 1, 1-dimethyl urea,** have shown excellent promise for controlling weeds in cotton. These herbicides are highly potent however and thus demand high accuracy in application to avoid overdosage. The limits of safe application rates for cotton on most soils vary between ¼ and ½ pound per acre on a 12-inch band basis. Over-dosage is not only hazardous to cotton but at rates higher than these the materials persist in the soil and may injure certain crops planted following cotton. The ureas should not be applied twice to a cotton field during a single season and if used, band treatments rather than broadcast applications are advised. Although extremely promising, the urea herbicides should not be used on cotton, except on a limited basis, until the importance of the chemical residues in the soil is clearly understood.

---

* CMU, available commercially as Karmex W and Telvar W.
** Available commercially as Karmex DL.

Other Herbicides: The substituted phenols or dinitro compounds are not recommended for pre-emergence use on cotton owing to several factors including their vapor hazard to the crop. Certain other chemicals under intensive study as pre-emergence herbicides are showing promise but more information is needed on their performance in different soils and under varying weather conditions before they can be considered for farmer usage.

CIPC Spray Mix: The manufacturer's label gives the number of pounds of active material per gallon of the herbicidal concentrate, usually four pounds per gallon. Instructions on the manufacturer's label pertaining to personal hazards in handling should be read and strictly observed. The proper amount of the formulated CIPC concentrate is mixed with enough water to make a final volume of ½ or 1 gallon for each inch of band width to be sprayed. For example, 6 to 12 gallons of mixture would be applied per acre for 12-inch bands, provided the rows are spaced 40 inches apart. The volume of 12 gallons per acre on a band basis has shown no advantage over the 6 gallon volume.

Replanting: Adverse weather sometimes makes it necessary to replant cotton, including that which has received pre-emergence treatment; this failure to obtain or maintain proper stands after investing in an herbicide is an important limitation to the use of pre emergence chemicals. If replanting is necessary and the row is free of weeds, replant in the previously treated band without further seedbed preparation. In cases where compactness of the soil makes this impractical or the row is grassy, prepare the soil and replant in the conventional manner. Following repreparation of the seedbed no control of weeds by the chemical can be expected. Retreatment with CIPC following thorough seedbed preparation does not present a hazard to the crop and may be done if chemical control of the weeds is deemed necessary. In the event some farmers use the urea herbicides on a trial basis and replanting is necessary, retreatment should not be done under any circumstances.

Duration of Effectiveness: Under most conditions CIPC has given outstanding control of the troublesome annual grasses, crabgrass and Brachiaria spp. and satisfactory control of pigweed, morning-glory and certain other annuals. The material does not control perennial weeds such as nutgrass, Johnson grass, deep-rooted vines, etc. Pre-emergence treatment can usually be expected to control weeds in the treated band from 4 to 6 weeks. When the first weeds begin to appear in the previously treated band, post-emergence treatments with herbicidal oil should be applied. Weeds that escape pre-emergence control should be given post-emergence treatment before they develop beyond the seedling stage.

Post-Emergence Treatment. Weeds growing in the untreated middles must be controlled by cultivation without throwing any fresh soil or clods into the treated area. Soil and clods thrown into the treated area will contain viable weed seeds and the drill area will be roughened so that effectiveness of post-emergence oil or flame is reduced. Treated band centering on the drill must also be maintained free of weeds. To accomplish these two jobs, several combinations of materials, methods and equipment are available.

For controlling weeds in the drill area, it is recommended that one to three applications of a herbicidal oil be used, followed by flame cultivation or regular cultivation.

Herbicidal Oils: The oil used should be one sold as a herbicidal oil for cotton by a reliable concern. Three commercially available oils* have performed satisfactorily for several years in field tests. These oils are petroleum products containing no added fortifying agents. Certain pre-emergence chemicals have been used experimentally and on field scale trials to control weeds in cotton by post-emergence applications, but these treatments have often been hazardous to the cotton. These recommendations are for the use of non-fortified oils only.

Equipment: These oils must be applied from fan-type nozzles. The shield-type, parallel action applicators have proven fairly satisfactory. These applicators are recommended in combination with broad angle, low crown, high speed sweeps.

Operators who have other types of satisfactory applicators and ground working equipment should continue to use them. No piece of equipment studied, including the one above, has proven to be entirely satisfactory.

---

* City Service No-Weed Oil No. 1; Esso 38; and Lion Herbicide Oil No. 1.

The applicators are placed to the inside of the front sweep and at the midpoint in length of the applicator opposite the sweep wing. Each shield should be set so that the front end is approximately ¼-inch higher than the rear end. This will help the shields to slide over the soil rather than "cut in."

The shields should be at such a height that they tend to float along the soil surface. This positioning will allow the shields to remain on the soil with a minimum of "digging in" and prevent complete clearing of the ground when irregularities in the row are encountered.

Cloddy beds, uneven beds, extremely dry and powdery soil, and other undesirable field characteristics will affect adversely the performance of all types of equipment. Some of these conditions can be prevented largely by good seedbed preparation and maintenance of correct equipment settings; for others no preventive measures can be taken, but they can usually be overcome by special setting of equipment. Any such special setting of equipment should not be such that it will change the rate or method of oil application.

Field Application: One nozzle should be used on each side of the row and each nozzle should be 5 inches from the drill center. The two nozzles should be spaced and directed so as to prevent the two spray patterns from meeting head-on, as this might cause an objectionable deflection of the spray. Nozzles should be set so that the spray fan is horizontal and strikes the young cotton stem no higher than 1 inch from the ground level and gives adequate coverage of the weeds. The nozzles should be set so that they are 1-inch or less above the soil. A slight downward tilt may be given to the nozzles to increase the ease of keeping oil off the seed leaves of the cotton. It should be emphasized that if the downward tilt is excessive most of the oil will be undesirably concentrated on the ground at the base of the cotton stems and the band treated will be too narrow. The oil should settle in the 8- to 10-inch band centering on the drill.

The importance of keeping the oil on the lowest inch of the cotton stem can not be over-stressed. Oil applied high on the stem, on the bud, or on the leaves will injure or kill young cotton plants.

When the cotton seedlings have been out of the soil for 7 to 10 days (at least three inches tall) the first application of herbicidal oil application will be needed when any weeds make their first appearance in the treated drill area. If the cotton has been out of the soil for less than three weeks, from 5 to 7 gallons per acre of oil may be applied for the first application, depending on the amount of weed growth. After the cotton has been out of the ground for three weeks, or after the first application, no more than five gallons per acre should be applied at any one time.

Repeat the applications of oil as needed, except that they should be at least five days apart, and a total of no more than three applications should be made. Oil should not be applied after the bark begins to form or small bark cracks begin to appear at the base of the stem. Moreover, if there is any appreciable injury noticeable from previous oilings, more oil should not be applied until injury has healed .

More than three applications of oil, including applications after the formation of true bark, have been made without cotton injury. The risk of injury, however, is much greater than when three or fewer oilings are made prior to bark formation, and none after this time. Further work may extend the safe period indefinitely, but until this work is completed the above restrictions on the number and time of applications are recommended.

By the time the second or third application of oil is made, most of the weed seed near enough to the soil surface will have germinated and have been killed. This frequently means that no further weed control is needed in the cotton drill, provided no soil containing viable weed is thrown into the drill area during middle cultivation. Under such a circumstance, further weed control may consist of simply cultivating the middles while using a drill protecting shield, such as the one used for the application of the post-emergence oil. If this condition is not obtained, and further weed control is needed in the drill area, it is recommended that flame cultivation be used for the remainder of the program as this will do a good job of safely controlling the weeds. It will also maintain the undisturbed drill area, and thus tend to prolong weed control.

Precautions. Any equipment used for applying 2,4-D should not be employed for applying insecticides or herbicidal oils to cotton or other broadleaf crop plants. It is safe to spray livestock with 2,4-D sprayers but after each use the spray tank, lines, nozzles and pump should be drained and washed thoroughly with water containing a good household detergent. The tractor used in spraying 2,4-D should be thoroughly washed or steamed before using in growing cotton. Only the amine salts and low-volatile esters of 2,4-D should be used for weed control. Vapors arising from fields sprayed with volatile esters may cause serious injury to growing cotton and certain other plants.

If cotton is growing adjacent to fields being sprayed with 2,4-D, there is considerable risk of injuring the cotton seriously, particularly if wind is blowing toward the cotton. If calm periods during the day are chosen for applying treatments of 2,4-D and low spray pressures are employed, it can be applied safely to fields adjacent to cotton. If corn is being treated, it may be advisable to leave a few rows of corn untreated next to the cotton to serve as a buffer against spray drift.

Before using any herbicide read and observe the manufacturer's instructions on the label of the container that pertains to hazards involved in handling and applying the materials.

SOYBEAN (South Area). For trial use a pre-emergence application of CIPC at planting time is suggested where crabgrass and *Brachiaria* species are troublesome. Dosages should be 1 to 1½ pounds per acre on a 12-inch band basis. Seed bed preparation and application of sprays should be done in the same manner as recommended for cotton. The pre-emergence treatment is not recommended for use on heavy clay soils such as Buckshot, Houston, etc.

A single directional spraying with one of the herbicidal oils recommended *FOR COTTON* has given good control of most young annual weeds in soybeans when applied correctly and at the proper time. An oil treatment of 5 gallons per acre when the soybeans are from 12 to 16 days past emergence and applied exactly as prescribed for use in cotton, is recommended where no pre-emergence chemical is used and an early annual weed problem exists. Under no conditions should the rate of 5 gallons per acre be exceeded.

PERMANENT PASTURE. With the trend toward increased grassland farming, the control of weeds in pasture is becoming a more serious problem. In order to help insure a maximum return from a pasture program it is essential to control weeds competing with grasses and legumes. Until recently the mower has been the only means the farmer had of keeping weeds under control, but now 2,4-D can be employed safely to control most broadleaf weeds which infest permanent pastures. If done according to recommendations, mowing will give fair control of weeds, but in many cases the practice is not closely adhered to or is restricted because of terrain features.

Studies conducted since 1950 indicate that the following recommendations are sound and worthy of wide employment on permanent pastures infested with broadleaf weeds.

Use ⅔ to 1 pound of the amine 2,4-D per acre in 10 to 20 gallons water as a broadcast spray application. First treatment should be made in early summer (April-May), followed by a retreatment in midsummer (July), if needed.

Pasture grasses and legumes should be well established and the weeds should have emerged but should still be small when treatment is made. It is hazardous to treat seedling grasses or legumes. Treatments should not be made during long droughty periods because stunted or slowly growing weeds are somewhat resistant to the 2,4-D spray.

Bermuda grass, Dallis grass, fescue, Johnson grass, white and ladino clover, lespedeza and black medic are not injured to any significant extent by the treatment. Plant growth may be retarded for a short period in these plants but they quickly recover. Pasture species severely injured by 2,4-D are crimson clover, red clover, bur clover, hop clover, vetch, and wild winter peas.

Excellent control of most broadleaf weeds such as bitterweed, tarweed or sumpweed, ragweed, boneset and sneezeweed can be expected.

Observe all precautions on the label of the 2,4-D container and exercise extreme care to prevent drift of spray to growing cotton and other susceptible crop or ornamental plants.

Turf and Lawns

About 15 materials have now been established as useful for turf and lawns, depending on the purpose of the user. None of these materials are good for all purposes. Broadleaf or herbaceous weeds may be controlled with 2,4-D. Endothal (3,6-endoxohexahydrophthallic acid) and 2,4,5-T are effective on clovers.

Maleic hydrazide can be used for special conditions, as along highways where a grass growth inhibitor is needed. Potassium cyanate, Crab-E-Rad, PMAS, Alanap, and some others are effective on crabgrass.

CRABGRASS. Some of the materials that have shown some promise in controlling crabgrass seedlings are listed below. The dosages listed are experimental. The user should follow the dosage and application dates listed by his local experiment station and by the manufacturer. Usually 2 to 3 applications are required. The tiny, young seedlings are much more susceptible than old grass.

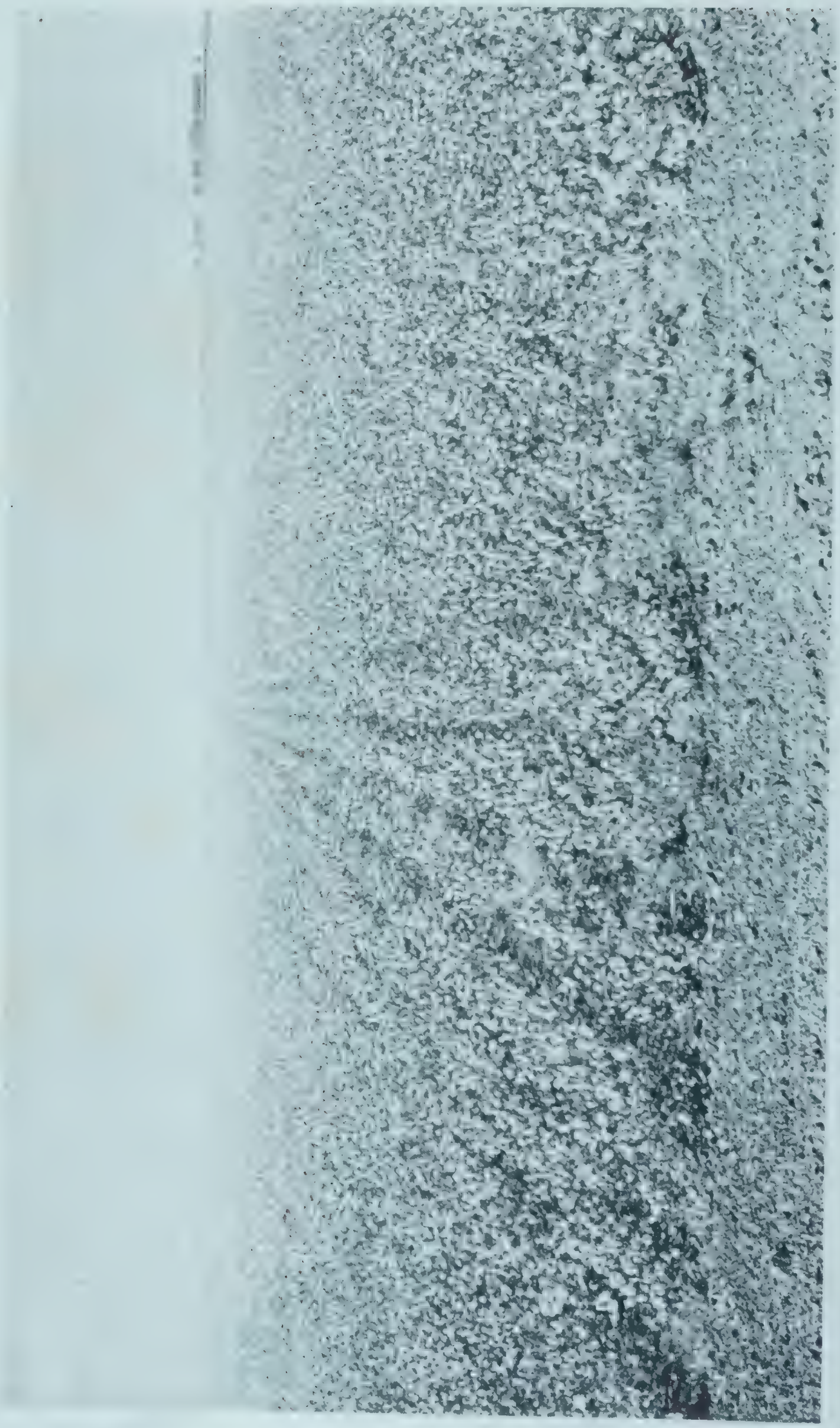
Precautionary measures are necessary to avoid injury to turf and ornamentals by herbicides. Degree of injury depends on the dosage as well as the kind of chemical. In some experiments by Hart and DeFrance (1956) they ranked the turf discoloration from greatest to least for several chemicals as follows: "Methar, Benzar, sodium arsenite, American Cyanamid mixtures Nos. 1 and 3, Di-Met, Crab-E-Rad, PMAS, and Scutl."

Some crabgrass materials are listed below, together with the per cent active ingredient in each, and some experimental dosage rates:

1. Crab-E-Rad (31.5% disodium methyl arsonate) at the rates of 10.75, 21.5, and 32.25 pounds per acre.
2. Di-Met (18.9% disodium methyl arsonate) at the rates of 10.75 and 21.5 pounds per acre.
3. Benzar (20% disodium benzyl arsonate) at the rates of 4 and 6 gallons per acre.
4. Methar (50% disodium methyl arsonate) at the rates of 8 and 12 pounds per acre.
5. Sodium arsenite (90.67% sodium arsenite) at the rates of 25 and 50 pounds per acre.
6. PMAS (10% phenyl mercuric acetate) at the rates of 6½ and 10¾ pints per acre.
7. Scutl (0.74% phenyl mercuric acetate impregnated in vermiculite) at settings No. 7 and No. 9 on the Scott's spreader.
8. American Cyanamid mixture No. 1 (4% potassium cyanate plus 96% Milorganite) at the rates of 43 and 64½ pounds per acre.
9. American Cyanamid mixture No. 3 (4% potassium cyanate plus 95% Nitrorganic Tankage) at the rates of 43 and 64½ pounds per acre.
10. Copper sulphate (99% copper sulphate) at the rates of 21.5 and 43 pounds per acre.

Chemical Defoliation and Desiccation With Concentrated Sprays

A NEW phase of concentrate application involves the use of chemicals to effect premature defoliation; or to desiccate seed crops like legumes so that they may be combined directly after treatment to prevent seed loss, and to accomplish other advantages. This procedure has been very useful for certain crops. Its value for various other crops awaits further exploration.



Effect of defoliant application on a cotton field near Plainview, Texas

Chemical Defoliation of Cotton

(Prepared by Steering Committee,*
Beltwide Cotton Defoliation Conference, 1953)

What is Defoliation?

INHERENTLY, cotton is a perennial plant with a natural process for shedding mature leaves. Shedding is the result of new cell growth at the base of the cotton leaf-stalk, where it joins the stem or branch. The cells multiply, form a thin abscission layer, and eventually separate, freeing the leaf from the plant.

This is defoliation. It can be brought on by drought, disease, plant food deficiency or light frost. The process can be artificially speeded up—and timed for the benefit of the cotton grower—through use of chemical cotton defoliants.

Defoliation versus Desiccation

What is the difference between *defoliation* and *desiccation?* The essential difference is in plant reaction to the chemicals. When we *defoliate* we are merely hastening a normal plant function—i.e., removal of leaves. When we *desiccate,* we cause rapid drying of leaves and other plant parts by chemical action.

Most of our present defoliants are contact herbicides. At certain rates, they will cause defoliation. At higher rates they can rapidly dry up leaves and other plant parts with little or no leaf drop.

Other chemicals, as pentachlorophenol in fuel oil or emulsion, can cause even faster killing and drying of the plant. But they, too, cause only a few leaves to shed; often none fall till they crumble, and blow away.

Desiccation is indicated where there is a need for drying up of all plant parts to improve stripper harvesting efficiency. But *caution is a must with desiccation,* for it interrupts boll development quicker than the milder-acting defoliants. Thus, there is greater danger of reducing lint yield and quality.

So, where desiccation is recommended, growers should not apply the chemicals till all 80 per cent of the bolls are open. This contrasts with a former recommendation that 50 to 70 per cent of the bolls be open before defoliation.

Why Defoliate?

Cotton growers may benefit from chemical defoliation in many ways. Here are some of the main ones:

---

* National Cotton Council, P. O. Box 18, Memphis, Tenn.

- Mechanical harvesters do a better job on defoliated cotton. Leaves don't clog spindles of mechanical pickers, add trash to stripped cotton, or stain lint. Defoliation helps large plants straighten up, and improves machine harvesting efficiency.
- Fiber and seed deterioration is retarded when defoliation allows lint more exposure to sun and to air movement. Bottom defoliation helps reduce boll rot.
- Defoliation aids hand pickers. When plants are leaf-free, dew dries more quickly, and pickers can get an earlier start.
- Leaf removal lowers populations of damaging insects, particularly aphid, boll weevil and leafworm. Because defoliation speeds up cotton harvesting, stalks can be destroyed earlier; this is especially important in areas where community-wide plowup programs aid in pink bollworm and boll weevil control.

Timing—Key to Profitable Defoliation

Timing, more than anything else, determines how much benefit a grower will get from defoliation. Unfortunately, there is no pat formula for figuring out when to apply defoliants. Correct timing may vary from year to year, from region to region, even from farm to farm.

For any given farm there is an "ideal" time to defoliate for most complete leaf removal. But this does not always coincide with the "ideal" time to defoliate for greatest benefits. This is an important distinction for the cotton grower to make—because, after all, his goal is to get the greatest benefits from defoliation.

Determining the right time to defoliate is simplified if the grower does a careful job of planning and growing his crop. There are several things he should keep in mind:

- He should make every effort to get an even stand of cotton, in order to promote uniform plant development and boll maturity.
- He should use enough fertilizer to insure continuous plant growth. It is equally important, however, to avoid excessive fertilization, particularly with nitrogen; delayed maturity or second growth is less likely if plants have exhausted readily available nitrogen by the time the crop nears maturity.
- Ample moisture throughout the season is essential. Farmers equipped to water their crops should not let plants become severely wilted between irrigations.

- Insect control is necessary for efficient defoliation. By following state insect control recommendations, growers can prevent attacks which interrupt continuous development of a full boll load and interfere with defoliability.

Careful attention to the points listed above simplifies the problem of timing. But the final decision on when to defoliate depends on: (1) condition of the cotton plant; (2) timing for machine harvesting; (3) whether boll rot is a problem; and (4) anticipated weather conditions.

Condition of the Plant

Mature plants defoliate best and most completely. For best results the boll-load should be heavy and vegetative development almost stopped. Plant and leaf moisture content must be high, because defoliation depends on the plant being in an active state of growth.

Bolls must be mature enough so that yields will not be reduced or fiber and seed quality lowered. Little damage will occur when bolls are full-sized and firm to the touch. Where late bolls mature rapidly there may be little loss of those 30 days old. Where bolls mature slowly there may be damage to yield and quality of any bolls less than 35 to 40 days old at defoliation time.

Timing for Mechanical Harvesting

For spindle picking, applications should be made so that a once-over picking can be completed shortly after defoliation—before the plant can develop a second growth of leaves that are hard to remove with chemicals. This means that the grower with a limited number of spindle pickers available must defoliate some fields later than others.

Where mechanical stripping is planned, application should be timed so that all leaves will shed prior to the average date of the first killing frost. All bolls should be open before stripping begins.

Boll Rot

If rainy weather or humid conditions prevail, open or mature bolls of the bottom crop may rot quickly. Defoliants may be applied solely to reduce further deterioration.

If the top crop is not sufficiently mature at this time, the grower must decide whether he will gain more by reducing rot than he might lose through immaturity of the top crop. Then he must time his application accordingly.

In some areas the practice of bottom defoliation is being explored. The idea is to control deterioration of the bottom crop without seriously checking development of late top bolls; in some cases, this also will permit an earlier first picking. In irrigated areas of the West, where large plants and high yields make it economical, this practice is gaining favor.

Weather Conditions

Weather should always be considered in timing the application of defoliants. It can have a marked effect on the mechanics of application, on the rate of defoliant required, and on the speed of leaf fall.

Temperature must be moderately high to insure rapid shedding of leaves; cool weather slows up defoliant action. On the other hand, temperature shouldn't be excessively high; otherwise, leaves will dry up too fast, break up before they fall, and become a troublesome source of trash in lint.

Efficiency of some dust defoliants depends on either dew or high humidity. Spray defoliants aren't entirely dependent on atmospheric moisture, but many are more efficient if applied when humidity is moderately high.

Wind affects efficiency of application. Even in moderate winds, dusts are hard to distribute thoroughly. High winds interfere with spray defoliants, though slight breezes often improve distribution.

Forecasts of the U. S. Weather Bureau will aid growers in timing defoliant applications. In some states, through cooperation of the Bureau, extension services, and other agencies, specialized weather information is available to farmers; frequent radio broadcasts give prediction of rain, dew conditions, humidity, wind velocities, temperature and other useful data.

Types of Defoliants

There are two general types of cotton defoliants, dust and spray.

For calcium cyanamid dust, a dew, mist or some other prolonged source of moisture is necessary. The time interval when moisture must be available on the leaf surface may be shorter, however, if leaf moisture content and temperature both are high. Dew is not necessary for monosodium cyanamid dust because the chemical draws moisture from the leaf or air as humidity rises; this defoliant works best when foliage contains ample moisture or humidity is moderately high following application.

Spray defoliants may be used under arid as well as humid conditions. Dew is not necessary and leaf moisture need not be as high as when dust is used. But if leaf moisture is low and leaves are tough, application rates must be increased; this often causes much leaf desiccation, slower leaf fall, and some freezing of leaves to plant.

Application

In applying defoliants, each leaf that is to shed must receive a covering of the chemical.

Equipment used for applying insecticides, either ground or airborne, also may be used for distributing defoliants. However, there are some differences in the physical makeup of insecticides and defoliants, and ground machinery must be adjusted to provide correct application of defoliants.

Tractor-mounted sprayers may be used in areas where the cotton plant does not grow large and limbs do not lap in the middle. To obtain adequate coverage of the plant, additional nozzles may have to be added. Nozzle tips suitable for defoliants must be installed.

When tractors are used to apply defoliants, wheel fenders should be installed to reduce damage to the crop. Such fenders are now being manufactured commercially. Instructions on making fenders in the farm workshop are available from some state extension services. In recent years a number of high-clearance machines have appeared on the market. Possibilities for using such machines in defoliation of rank cotton are being studied by research authorities in several states.

Airplanes have been used extensively for applying both dust and spray defoliants. More uniform coverage and proper swath widths are likely when flagmen assist aerial applicators.

Defoliation in Different Areas

Defoliation problems and practices vary widely in different parts of the Cotton Belt. Here are some of the general conditions that affect use of defoliation in main cotton-growing areas:

South Atlantic* and South Central.** Rainfall is usually ample: growth often profuse where fertility is adequate; dews frequent and heavy; plants seldom "cut out" sharply unless late-summer drought or low fertility limits growth and fruiting; second growth usually occurs early in fall; defoliants usually applied when youngest bolls expected to make cotton are not less than 32 days old; picking normally can begin 7 to 10 days after application.

Southwestern River Valley.†—Rainfall normally lower than in East; late-summer drought likely to toughen foliage; dews may be infrequent and short; plant growth and boll-load vary from excellent in fully irrigated locations to poor in dry-land sections; plants often cut out sharply in drier seasons but second growth may become profuse after early fall rains; youngest bolls should be at least 32 days old before defoliant application; leaf fall may be slower than in the East; higher application rates needed for drought-toughened and poorly-fruited plants.

Western Plains.††—Season short and rainfall may be low throughout; plants short though heavily fruited, especially if supplemental irrigation is used; dews infrequent and don't last long; wind, arid climate, and drought often produce tough leaves that react slowly to defoliants and require higher rates; plants may cut out sharply; second growth usually delayed until fall rains; defoliant normally applied when youngest bolls are at least 35-40 days old. Leaf fall often slow; growers allow two to three weeks before stripping begins.

Far West.*†—Nearly all cotton of Acala variety; grows tall and leafy; usually fruits heavily; dews rare and short, though occasionally adequate for dust defoliation; strong desiccation tendency between last irrigation and time that top crop is mature enough to be undamaged by defoliation; bolls large, slow to mature; youngest bolls should be at least 35, often 40 days old at application time; second growth can be profuse if soil retains moisture from late irrigation, or if fall rains come after crop is fully mature.

---

* Includes North Carolina, South Carolina, Georgia and Florida.

** Includes Alabama, Mississippi, Tennessee, Southeastern Missouri, Eastern Arkansas, Eastern Louisiana.

† Includes parts of Western Arkansas and Louisiana, Southeastern Oklahoma, the Texas Gulf, the Lower Rio Grande Valley, and the Black Belt area of Texas.

†† Includes High Plains and Rolling Plains of Southwestern Oklahoma and Northwestern Texas.

*† Includes cotton areas of Arizona, California, New Mexico, and El Paso region of Texas.

Defoliation Terminology

Freeze—to kill the leaves and make them adhere to the plant.

Desiccate—To dry out all tissues of the leaf blade and leaf stalk.

Abscission—Process of shedding leaves by multiplication, growth and separation of cells at the base of the leaf-stalk.

Maturity—Stage when plant's activity directed mainly toward maturing its bolls, rather than toward developing new fruit and vegetation.

Plant and Foliage Activity—Refers to growth processes, which must be at a high level for leaves to react properly to the defoliant. It is mainly dependent upon ample moisture in plants.

Cut-Out—Cessation of boll setting at the end of the growth period. This may be sharp and easily recognized in certain areas, but is usually hard to identify.

Warning

BEFORE using any defoliant, study all instructions for using it. Certain defoliants, if mishandled, can damage other crops and farm equipment. Defoliants also can be dangerous to animals and to humans. Should any unusual illness occur after working with defoliants, consult a doctor at once.

Desiccating Seed Crops With Concentrated Sprays

WHERE successful, desiccation may have the following advantages:

1. Permits combining a dry standing crop, eliminates windows, and reduces associated handling losses.
2. May reduce "shattering" due to adverse weather conditions and other factors.
3. Desiccated crops may combine easier and faster.
4. Certain attendant weeds which reduce seed quality may be eliminated by drying.

It is of interest that proper treatment does not reduce germination or regrowth of established perennial crops. Considerable success with desiccating materials has been obtained with the following crops: Alfalfa, clovers, trefoils, vetches, lespedeza, beans, oats, rice, soybeans, and grasses (rescue, fescue, and orchard grass).

WHEN TO SPRAY: The crop should be sprayed at the time it could ordinarily be cut for windrowing or drying. Spraying too early before seeds are ripe may result in shriveled seed and reduced yield and germination. A repeat application may have to be made if much rain occurs within 4 to 6 hours after treatment.

Crops that normally shatter readily when dry should be combined as soon as possible. Growers of birdsfoot trefoil probably should not spray larger areas than could be handled in a few days' combining operations because of a tendency of seed pods to shatter when rained upon. White clover should be combined within 4 days after treatment as it has a tendency to become lodged if allowed to stand too long in the field.

How to Spray: There are a number of very promising desiccating chemicals. One of them is Endothal (3,6-endoxohexahydrophthallic acid). Normally apply 1 gallon of Endothal per acre diluted with enough water to give adequate coverage. For best results in dense, rank, irrigated crops use 1½ gallons Endothal. For *aerial* applications, total spray volumes of 3 to 5 gallons per acre have proved entirely satisfactory under most conditions. Where growth is extremely dense or where no non-drying liquid is added to the mixture in hot, arid areas, a volume of 10 gallons per acre may increase efficiency. For low gallonage *ground* equipment, 10 to 15 gallons per acre are suggested, the higher volumes being recommended for dense growth and conditions favorable for rapid drying of the spray.

Caution: When Endothal and certain other chemicals are applied, the seed may be used for planting purposes only, and other portions of treated plants should not be used for feed, food, or forage. Spray drift to trees, plants, or crops not being treated may result in injury. Do not swallow Endothal or allow it to get into the eyes. Read the package label carefully.

Health Problems

Ragweed

THE chief plant offenders are ragweed and poison ivy. Some 5 to 7 per cent of people east of the Mississippi suffer from hayfever. About 80 per cent of them are affected by ragweed and a large percentage of these develop asthma after repeated attacks of hayfever. A few people develop a dermatitis when they come into physical contact with the ragweed plant.

The ragweed problem and the poison ivy problem are man-made. Some 60 to 65 per cent of ragweed is along streets and roads where the soil was disturbed. It can be cut or easily sprayed. Most of the remaining 35 to 40 per cent is along turn rows, at the ends or edges of fields, and in vacant lots. One does not often find it in well-stocked clover, turf, grass fields, or in woodlands.

The effective control of ragweed depends on the prevention of seed production and fertilization. An effective aqueous foliage spray contains ½ to 1 pound of acid equivalent 2,4-D per 100 gallons of water for the full dilution sprays. Use 100 to 300 gallons per acre depending on plant size and density, so as to drench the foliage with coarse spray. If the concentrate or low gallonage technic is employed, the quantity of acid equivalent may be reduced to ¾ to 1¼ pounds per acre. Ester formulations should not be used in the vicinity of desirable plants that are susceptible to 2,4-D. Spraying should not be done on windy days because of drift. Best spraying conditions prevail during early morning and late afternoon.

Spraying ragweed not only prevents pollen and seed production, but has a cumulative effect. Future ragweed growth is discouraged through the stimulation of competing vegetation, especially grasses. The control of ragweed with 2,4-D in urban areas has been effective and economically feasible, as well as beneficial to hayfever sufferers within such areas. Control along highways and railroads is highly desirable to complement and supplement urban control programs.

The time period for spraying in any community depends on equipment and manpower available in relation to extent of weed growth to be sprayed. When spraying can be completed in a few weeks, it should be done as late as possible during the growing season and still be completed by the first week in August. Most municipalities find it desirable to conduct weed control programs with several departments cooperating. Such departments include: health, public works and parks, and public roads and highways. Keepers of golf courses, cemeteries, water companies, factories and private estates should also be enlisted.

Two types of programs providing maximum control are: First, the control of extensive and concentrated ragweed growth in urban areas where the largest number of people will benefit with the least per capita cost, and second, the control of ragweed along highways and railroads where people travel between home and work.

EQUIPMENT: See Chapters II and III for equipment and application methods.

Programs and problems needing more work are:

1. The cooperation of specialists, including aerobiologists, botanists, statisticians, public works engineers, sanitarians, agricul

turists and public health administrators, is essential in solving the problems of control and in evaluating control programs.

2. Research to determine the concentration and dynamics of pollen in the atmosphere necessary to bring about allergic reaction. What are the relative effects of pollen concentration and nearness to pollen source. What is the relative value of given degrees of ragweed control of say 30 to 95 per cent in areas of given size? What is the rate of deterioration or loss of toxicity of the ragweed poison in relation to age of pollen grains, numbers of hours the grains are in the air, and the effect of sunlight and moisture?
3. The botanical and meteorological factors influencing the distribution of pollen in the air from the ragweed growing areas. On dry, hot days the pollen may be floated into and with the air for many miles, but the rate of air dilution is fantastic and the effective life of the exposed toxicant is relatively short.
4. Measuring devices including aerial types to quantitatively sample pollen in air. This is necessary to determine where pollen is coming from and to measure the reduction in pollen concentrations in the air following the elimination or reduction of ragweed growing areas.
5. Field surveys of states or regional areas to determine the location, extent, and intensity of ragweed infestations.
6. The development of control programs on a regional basis.
7. Research is needed in plant ecology, including the effect of weed killers on plants and on the use of competitive plants to compete with or suppress ragweed growth in places where competitive plants are now discouraged by an unfavorable environment. More information is also needed on ragweed life history to better understand the problems of control.
8. The development of practical control measures for ragweed in connection with the growing of crops such as corn, cotton, potatoes, tomatoes, grain, etc.
9. The encouragement of private organizations, financed by public contributions, that are dedicated to the relief of hayfever sufferers. For more information see Fletcher (1955).

More equipment research and testing would be helpful, and potential users should be supplied with the best information on equipment, specific chemicals, formulations, spraying methods, proper nozzles, pressures, technique of application to the plant, and chemical hazards.

Poison Ivy

In many suburban-type communities where poison ivy and poison oak has been allowed to grow unchecked, as many as 20 to 25 per cent of the population are poisoned from contact with this plant each season. Poison plants killed by chemicals retain some of their poison for a considerable period after they turn brown and appear dead.

Poison ivy is found in wood lots, along fence rows, in parks and school playgrounds and in other recreational areas, as well as growing on trees, poles, and in orchards. It can be effectively controlled with sprays of ammonium sulfamate, 2,4,5-T, combinations of 2,4-D and 2,4,5-T, and amino triazole. Amino triazole is the most effective poison ivy spray chemical to date and can be used as low as 3 pounds of actual toxic per 100 gallons of full dilution spray; or 4 pounds per acre when used in the form of concentrated spray (essentially one ounce per 700 sq. ft. or 1.44 per 1000 sq. ft.) Borax has been effective at four pounds per 100 sq. ft. or 40 lbs. per 1000 sq. ft. Higher dosages of chemicals are necessary to kill poison ivy growing in the shade than in the sun.

Problems needing more work are studies of penetration, absorption and translocation of herbicides in the poison ivy plant and the influence of life history and time of application on effectiveness of treatment. Research is needed to determine uniform applications of lethal amounts of herbicide to control poison ivy and in the testing of wetting, spreading, and coating agents.

Potential users should seek the latest and best information on spray equipment and methods.

Other Health Offenders

A statement on health hazards would not be complete without mentioning the weed, marijuana, which grows wild in many states. It is used as a narcotic drug, and while the major problem of drug control involves the international interstate control of the drug traffic, the growth of this plant in many areas should be eliminated (Ahlgren, 1955).

Finally, various weeds affect health adversely in a number of miscellaneous ways. Some are toxic when consumed and others are injurious to fish and to the marine life and affect the quality of the water used for swimming and for drinking. Some cause an unsightly and odorous scum. Weed growth may provide hiding places for harmful insects and plant diseases and may block drainage, thus contributing to mosquito breeding or even the development of pollution. Thick growth of tall ragweed prevents the inspection and spraying of stagnant water for the control of mosquitoes. Cleaning of drainage ditches to promote better mosquito control frequently promotes the growth of ragweed on the ditch banks and thereby increases the pollen concentration.

Highways and Herbicides

IT may not be just coincidental that the recent trend towards wider rights-of-way and increasing public demands for greater comfort, safety, and scenic beauty has followed closely behind the development of new herbicides, pesticides, and chemical application technics. The new approach is not merely for effecting road safety and beauty. It is also aimed at promoting health, less driver fatigue, sound abatement, dust screening with plant and tree foliage, air draft removal of exhaust fumes, and more shade for cooling effect. Moreover, chemicals, and particularly herbicides and silvicides, are tools for doing the job better and more economically than the old methods. This gives rise to new opportunities, and to new responsibilities as well.

New Type of Highway

Many engineers feel that the New Jersey Garden State Parkway and the Connecticut Merritt Parkway, averaging 22 roadside acres per mile with right-of-way up to 300 feet, are prototypes of future interstate highways. In fact, the latter can be much improved over the former with more parkway atmosphere and built-in recreation, health, safety, and scenic features.

Actually, the new type of highway expansion is creating a new type of acreage in the national economy. This acreage consists of roadside areas, including parks, picnic areas, and median strips in dual highways. Some roads will run through woodlands and some will be in open areas requiring a different type of planting and treatment. To maintain economically the new type of landscaped acreage of beautiful turf, shrubs, flowers, and trees will require weed and brush control, nutrient application, the use of grass growth inhibitors to reduce mowing, and insect, tick, mite, and chigger control in roadside wooded areas, picnic grounds, and parks. It is anticipated that some 5 to 10 billion dollars annually may be spent in building and maintaining new highways, eventually including as much as 100 million dollars annually for pesticides and the acquisition of perhaps as many as 3,500 power pesticide applicator machines. To carry out efficiently the responsibility of this undertaking, the writer suggests suitable spray schedules, short courses of instruction, short course laboratory and field training schools, educational programs, and demonstrations, and of course, research programs are needed on a regional basis, at least.

How many acres will be involved? No one knows exactly, but according to Long (1955) one state—Ohio, can be compared as follows:

"Ohio has 18,000 miles of state roads and 70,000 miles of secondary roads with an average of slightly less than 4 roadside acres per mile of highway. Ohio's roadside area already totals 330,000 acres, equivalent to 3,300 average size Ohio farms. There are some 700,000 miles of highways in the country's federal aid primary and secondary systems. The total strip and border area for the nation is estimated to be about 60,000 square miles, or an area equal to or slightly exceeding that of the state of Georgia." If that is true, does it not behoove foresters and conservationists to be concerned with the size, kind, use potential, and location of areas that go into this roads domain, as well as the way in which it is to be managed?

Use of Herbicides

SAFETY features: Controlling brush and weeds along roadsides is a continual problem in keeping roads and highways safe. Uncontrolled vegetation often creates a safety hazard by obstructing motorists' visibility, obscuring warning signs and traffic signals and cutting off the view at curves, cross-roads and driveways. If it crowds in too close to the road shoulder, it makes the road dangerously narrow for two cars passing each other, for roadside parking or for pedestrians walking beside traffic lanes.

Trees and other plants in the right places can minimize light glare and noise, and screen out dust. If trees, tall weeds, brush and other objects are in the wrong places, they can obstruct the driver's view and cause accidents.

Brush may interfere with drainage, causing unexpected patches of snow, ice or water. Working crews need space to work safely along the roadside and to park their trucks and other equipment where they will cause the least traffic obstruction.

PRECAUTIONS: Since the use of herbicides on established vegetation means killing such vegetation with its resultant change in appearance, chemical weed and brush control is sometimes objectionable to a public not familiar with its purpose or end results. Also, these chemicals are potentially dangerous to vegetation adjacent to the right of way as well as on the right of way.

Because of these two factors—possible objectionable appearance and potential off the right of way damage—chemical weed and brush control places a heavy responsibility on applicators to do the job properly.

Sometimes both the general public and the adjoining property owners may react adversely to the use of chemicals. Such reaction at times is justified and at other times is entirely unjustified. To forestall criticism of herbicide use requires that the safest possible materials be applied with the proper precautions.

An unjust, uninformed or unreasonable censure of the use of herbicides requires a constant educational campaign on the part of all concerned in their use. Highway officials are justified in insisting on the use of chemicals where they result in greater convenience and safety to the traveling public or in lowered maintenance costs.

The first general public reaction to chemical weed and brush control may be adverse because of the brown appearance following chemical application. The citizen out for a Sunday afternoon drive may visualize a permanently brown and desolate roadside. He should be told, through what media are available, that even "blanket" spraying is selective in that it kills chiefly the woody growth and the coarse weeds.

"Brownout" is most noticeable at the time a roadside is first put under a chemical control program. As the weeds and brush remaining to be affected by the chemicals become less each year, so does the noticeable amount of browning that takes place.

Weed and brush control can be accomplished without the "brownout" if we are willing to pass up the brush with only light dosages until it can be cut. After cutting, the cut surfaces should be sprayed immediately to prevent sprouting. This involves spraying for the weeds first, reducing the dosage per acre by ⅓ to ½, and making 2 or 3 applications beginning about the first of May in the Northeast and continuing until September. The weeds are more important than the brush, for brush exists only here and there along most of our roads, whereas weeds fill part of our roads practically everywhere. Where poison ivy exists it should be sprayed to death to make the cutting safer.

Most commercial operators use a mixture of 2,4-D and 2,4,5-T for general weed and brush control. In any case, we must take a close look into the growth along our roadsides and determine what is there. We must know what weeds grow in spring, summer and fall; when they germinate and when they seed.

Wild Life. Criticism is often heard that chemical control of roadside vegetation affects wildlife adversely. However, results of several tests indicate that wildlife cover is improved through herbicide use. The practice of chemical weed and brush control is a question of good land management. Actually, many food and shelter producing plants remain for birds and animals even after "blanket" spraying.

It has been estimated that in a single state in the Northeast, 57,600 rabbits were killed along highways in 1952. What would have been the figure if their cover had been eliminated along a strip 16 to 20 feet wide on each side of every road?

It seems questionable if roadsides should be so treated or managed that they furnish a game preserve with an open play space—the traffic lane—in this day of high speed traffic. Vegetation control eliminates protective cover from which small game may suddenly dart into the path of motor vehicles.

Herbicides can be used to solve vegetation control problems in any roadside maintenance program. They are particularly suitable where the terrain does not lend itself to mechanical mowing. They are also of special interest where elimination of woody growth or coarse herbaceous vegetation is desirable, with consequent encouragement of low growing grassy cover.

Operation Along Roadways

EFFICIENT operation is required for successful weed and brush control. A number of herbicides have their place in roadside spraying. They include low and non-volatile 2,4-D and 2,4,5-T, Silvex, amino triazole, ammonium sulfamate, Dalapon, Erbon, Alanap, CIPC, TCA, monuron, diuron, sodium chlorate, borax, borates, petroleum solvents and oils; and maleic hydrazide as a grass growth inhibitor to reduce mowing. Health problems along highways have just been discussed. Equipment and formulation methods have been presented in Chapters II, III and V. A few operational observations are given below that may not have been sufficiently covered in those three chapters.

The operator of spray equipment must plan the number of miles it can handle during the growing season. To do this he must determine how many times each mile of road is to be sprayed, the width of strips, the acreage, the rate of travel of the machines, and the number of gallons per acre. He must select the right herbicides and dosage and the proper nozzle, pressure, spray output, and drop size to give the best coverage and the least drift hazard. Obviously, drift can usually be reduced by early morning and late afternoon applications to beat the winds. Thorough operator training is very essential.

Power spray equipment that does not leave the road pavement must be able to throw for considerable distance from the machine and must take care of changes in swath, width, slope, and elevations. There must be provision for quick changes in nozzle size and direction.

One large scale operator uses a large right-hand-drive truck with four nozzles mounted on an approximately 6-foot, sturdy

Figure 152. Right-hand drive highway weed and brush control sprayer has 4 nozzles mounted vertically and controlled from cab. Low nozzle sprays beam to 24 feet. Upper nozzles cover close brush. Driver does all work.
Courtesy, McMahan Bros., Inc., Binghamton, N. Y.

vertical beam. A low position, solid stream nozzle sprays berm to 24 feet, while three fantype boomless nozzles spray brush and weeds close to the machine. The whole operation is performed by one man —the driver. The pump delivers up to a maximum of 20 g.p.m. @ 800 p.si., from a 3-speed power take off. This is enough to cover a 24-foot swath with essentially a 3/16-inch orifice in the solid stream nozzle. The truck travels at a fairly high speed. An average of 50 gallons of semi-concentrated material can be delivered per mile of road. As little as 25 gallons per acre can be applied. One such machine can make three treatments per year to about 600 miles of road at a charge of 29.5 dollars per mile. The spray deliveries for given rates of travel and swath widths are listed in detail in Chapter III.

The table below showing acres covered per hour was arrived at by multiplying acres per mile times miles per hour of travel.* The equipment is limited to the distance that it can throw from the paved strip, unless enough hose is used to reach 25 to 150 feet.

Width of strip	Acres per mile	Width of strip	Acres per mile
Feet		Feet	
6	0.62	30	3.63
10	1.21	50	6.04
12	1.45	75	9.06
16	1.93	100	12.1
18	2.18	150	18.14
20	2.42	200	24.2
25	3.02	300	36.3

* For example, a 25-foot swath at 10 miles per hour would cover 30.2 acres per hour. At 25 gallons per acre a delivery of 12.6 gallons per minute would be required.

The above discussion was on big, heavy, expensive equipment that requires big tanks and more spray solution than for high concentration sprays. Lighter equipment such as can be attached to small tractors and power lawn mowers has a place for the low gallonage application. This is especially true of areas that are beyond the reach of the big hydraulic sprayers as well as for strip and spot spraying. The compressed air and knapsack sprayers are also very useful for applying herbicide concentrates along highways, using the cone, oil burner type nozzles that deliver 2.5 to 6 gallons per hour at 20 to 30 p.s.i., to apply 5 to 10 gallons of mixture per acre. Solution and emulsion sprays are usually applied at 20X concentration of 5 to 6 gallons per acre of low vegetation, or 12.5 gallons per acre of good stocking of brush.

Precautions regarding chemicals and drift of fine spray around susceptible plants must be adhered to. Fine spray should not be released from a high position where it can be carried by the wind.

COST. Undesirable vegetation along roadsides has for many years required extremely large budgets for mechanical and manual control. Control problems involving weeds, brush, brambles and grass are now being solved more completely, satisfactorily and efficiently through the effective use of herbicides.

One of the most acute problems encountered in trying to establish weed and brush control programs along roadsides is that of maintaining a sustained program. This is particularly true in the case of weed control spraying where, as the program progresses, the results, per spray, appear to decrease application by application. As a result, it has been noted in many areas that public support for roadside spraying has appeared to decrease in the belief that a job had been accomplished and further applications would only be wasted.

The use of herbicides in many phases of roadside vegetation control is a well-established practice. Properly used, these chemicals lessen frequency of treatment and amount of labor and money necessary to maintain the areas outside the traffic lanes. To use them efficiently requires knowledge of the different chemicals and their methods of application.

Considerable cost data indicating the economies made possible by the proper use of chemicals for roadside maintenance have been published (see footnote page 473). A recent study of the uses of herbicides along highways has been discussed by Iurka (1956).

Mowing is a continuing and costly operation. One excellent cost study reports 4.3 acres mowed in a nine hour day by a sickle bar tractor mower and 1.75 acres by a small power mower. At $1.50 per hour for labor, this would be a cost of over $3 per acre for the former and over $7 for the latter for labor alone. One spraying of 2,4 D has been done for less than $3 an acre for labor and materials. The effect of this treatment which materially reduced the number of mowings necessary lasted more than one year.

Brush can be controlled by chemicals at a cost comparable to that for one or two cuttings by hand, the cost of subsequent control being negligible when chemicals are used and continuing when cutting is practiced.

Mowing of vegetation around structures such as guard rails and posts whether by hand or by equipment is expensive. Hand mowing[*] has cost almost $100 an acre or $35 for a swath three feet wide along one mile of guard rail. At least three such mowings[**] at a labor cost of over $100 for one season would be required to give results comparable to those obtained with chemicals. Since reporting tests of several materials for this purpose to the Northeastern Weed Control Conference,[††] one agency has used the highest rated material during the past four years at a cost of less than $25 a season for labor and materials for each mile treated[†]. Additional study is needed in this field due to the development of new materials such as Telvar W, Telvar DW and Dalapon.

McMahon (1956) describes the basic differences between the sprayer and mower as follows:

a. The sprayer moves much faster and there are no cut-off plant parts to be removed.
b. It affects growth the mower cannot cut or reach.
c. It kills the culprit plant instead of pruning it.
d. It is not subject to constant maintenance.
e. It encourages the growth of turf instead of weakening it by repeated cuttings which prevent the plants from storing up root reserve.
f. The work must be minutely planned to make each application as effective as possible.

Weed and Brush Control Along Utility Lines

MUCH of the preceding text was applicable to herbicide and silvicide application along utility lines. Therefore, the discussion below is limited mostly to the more specific problem and adaptations for right-of-way brush control.

The futility of *cutting* brush was expressed by a line superintendent of a utility company when he said "cut one 6-inch tree and next year you will have six 1-inch sprouts; cut them and next year you will have twelve or more sprouts where you had one 6-inch tree." (Carlson, 1953).

---

[*] "Connecticut Highway Maintenance Production Study"; Highway Research Board Special Report 8 (1952).

[**] "Roadside Vegetative Cover Research Project," *Progress Report*; Landscape Bureau, New York State Department of Public Works (March 1954).

[†] "Roadside Vegetative Cover," *Final Report*; Landscape Bureau, New York State Department of Public Works, March 31, 1954.

[††] "Progress Report on the use of herbicides to eliminate handmowing under guard rails and around traffic signs along New York Highways, Iurka and Pridham. Proceedings 5th Annual Meeting, Northeastern Weed Control Conference (January 1951).

In most respects suppression with chemicals has been a great improvement over that by men with axes and machettes. It is faster, cheaper, and more permanent. However, it does create new problems and new hazards to wild life and nearby crops that should be met. Furthermore, it is by no means "cheap," and the coverage rate needs to be speeded up considerably. Most conventional brush control spray jobs cost from 25 to 60 dollars per acre for the first spraying. Subsequent treatments usually cost less. The number of treatments required over a period of years will depend on the degree of control of the first application and the effectiveness of follow-up and spot treatments. It appears now that a good application of 2,4,5-T may not require respraying for 2 to 3 years.

Classification of Treatment: Application of brush control chemicals may be classified as to foliage, basal stem, and stump or stubble. Foliage application is the quickest and best adapted way to treat for the first time over to convert growth to a relatively non-woody plant area. This method is limited to seasonal operation.

Basal stem treatment is particularly useful to control sparse infestations inaccessible to spray equipment; and for treating stems that survive foliage applications. The treatment can be made at any time of season, preferably during the dormant period without chance of injury to sensitive crops. This permits use of man power during the off-season. Relatively inexpensive equipment is required. However, it is not as economical or as widely applicable as foliar sprays. A high labor cost is involved because each stem must be thoroughly wet on all sides at the ground line. To obtain desired results it is important to apply sufficient liquid to assure physical run-down outside the stem to the root crown, bud, or transition zone of the plant. Knapsack sprayers are more often used to apply the chemicals. However, a useful light power unit consists of a 4 h.p. gas engine, ½ inch gear pump, and two lines of light hose with a suitable nozzle, gun and shut off valve attached to each line of hose. The chemicals are used at 5 times the concentration of dilute sprays i.e., 16 pounds or more per 100 gallons of No. 2 fuel or diesel oil, or 1 pint in 2½ gallons of oil. To aid in marking, up to 60 per cent of the oil in the mixture can be supplied from strained black carbon waste oils of filling stations and garages. White strings may also be used to lay out spraying lanes of 40 to 60 feet in width to help guide the spray men.

Stumps should be thoroughly wetted at time of cutting to reduce sprouting. This practice is relatively inexpensive from a labor standpoint, especially when stump diameter is greater than two inches. Usually one man treats the stump diameter behind a regular cutting crew. Ammate may be applied as crystals at the rate of two ounces per six inches of diameter, or thoroughly wetting with concentrate solution at 4 to 6 lbs. per gallon of water. The 2,4,5-T esters are used at 16 to 20 lbs. per 100 gallons of oil (or one pint per gallon of diesel oil) to thoroughly wet the stump as for the basal stem application.

Foliage Sprays. The 2,4-D weed killers will control certain species as willow, alder, sumac, elderberry, brambles, raspberry, blackberry, and other easier to control woody plant. However, it is not sufficiently effective against most dominant hardwoods like oak, ash, hickory, and maple. For these and most other resistant woody species, 2,4,5-T is more effective than 2,4-D. A common mixture is one containing two powders: 2,4-D and two pounds of 2,4,5-T acid equivalent per gallon. Water is a cheaper diluent for it than oil. For the dilute or full dilution sprays, 3 to 6 quarts of 2,4-D—2,4,5-T mixture is added for each 100 gallons of water for foliage application.

"Ammate" is applied to foliage at the rate of 75 pounds per 100 gallons of water. Thorough wetting with a spreader-sticker is important. It is more expensive and is rough on equipment, particularly copper and brass gears and pipes. For semi-concentarte application concentrations up to 8X, or 6 pounds per gallon can be prepared Ammate is more nearly a "one-shot" treatment, making re-treatment unnecessary for several years because it effects an 80 per cent or better root kill of mixed species. Being non-volatile, there is less danger from drift.

Concentrated spray application with suitable equipment is highly effective and is discussed under *Equipment and Application Methods* (page 476).

Cost. Cost is the meat of any brush control program. To make an estimate, one must ask a number of questions. The answers to these questions will tell us which chemical we should use, how it should be applied, what concentrations, spray volumes, and types of equipment are best. Do we want all of the brush cleared or are we satisfied with thinning it out a bit? Is it composed of dense tall brush and trees or is there a clump here and there? What species are involved or predominant? Is the area readily accessible to spray equipment or will it require some special effort to get through and make the application? What are the hazards?

How can the cost of application be reduced and how can the speed and ease of coverage be increased? To answer these questions we must look to four categories as follows: (1) cheaper and more phytotoxic, selective chemicals, (2) effective methods for using less total chemical per acre, (3) methods for using less diluent and total spray volume per acre, and (4) cheaper, lighter, and more mobile spray equipment. In all of these categories except the first one, we must depend on equipment and application methods.

A gallon of 2,4,5-T concentrate containing 4 pounds of acid equivalent costs about 10 dollars. If 2.25 gallons of it are used in 225 gallons of full-dilution spray per acre, the cost of the chemical alone would be about 26 dollars, for application with conventional hydraulic machines. Some operators use 1½ gallons of brush killer in each 100 gallons of spray; and apply as much as 250 to 450 gallons of it per acre. Others add 10 to 20 gallons of emulsifiable aromatic oils per acre and even wet the stems down to the root crowns including all weeds and grass.

In a well stocked stand of mixed brush and undergrowth, 275 gallons were required to wet the foliage to the point of run-off without an emulsifying or wetting agent. If the same volume of mixture was applied with a water soluble wetting agent that reduced the surface tension to 32 dynes, the deposit was only 60 per cent as great as when the mixture contained no wetting agent.

Equipment and Application Methods. The conventional equipment ordinarily consists of a conventional piston type hydraulic sprayer (as Hardie, Bean, Iron Age, Myer, etc.) with ¾ inch high pressure hose. Nozzle sizes fit the pump capacity. The 15 g.p.m. pumps can use the 3/16-inch orifice but the 1/4, 15/16, and 5/16-inch orifices will require the 35 and 60 g.p.m. pumps which calls for a very *heavy* outfit.

In order to get through brush, over rocks, and over the hills the equipment is mounted on a 4-wheel drive power wagon truck, such as the Dodge power wagon. The crawler or caterpillar type tractors can carry smaller equipment through practically all power line and brush conditions where ordinary trucks and tractors are worthless.

The author set up a number of studies in an effort to beat down the costs without losing too much control effect. One was an attempt to see what reductions could be made in insecticide and in spray volume, using dosages of 1,2,3,4,6 and 8 quarts of 2,4,5-T ester per acre in 25, 50, 100, 200, 400, and 1000 gallons per acre. These experiments showed that (1) complete coverage of every leaf with hormone type sprays in brush control was not necessary, (2) one to six quarts of 2,4,5-T was not as effective in 1000 gallons of spray as it was in 100 gallons per acre, (3) in ordinary spray operations only 25 to 50 per cent of the spray is deposited on the foliage. Further studies indicate that good foliage kill can be obtained with 4 to 6 quarts of 2,4,5-T in 50 to 60 gallons per acre with the above equipment. This is a great reduction in both the total silvicide and the total volume of spray. It also speeds up rate of application and reduces labor costs.

The 2,4,5-T and various other hormone types are very effective when applied in the form of concentrated sprays. Knapsack sprayers or compressed air back sprayers may be effectively used to apply 1 to 1½ gallons of 2,4,5-T in enough water to make 5 to 10 gallons of total finished spray per acre. This gives no spray drip and run-off. The low gallonage used enables each man to cover 3 to 6 acres per day. This system is also very economical for spot spraying and for retreatment of old sprayed areas. It is limited by the fact that it cannot reach growth higher than 15 feet. A 6 to 8 foot aluminum extension rod is required. The nozzles are 2.5 to 6 g.p.h., cone types, oil burner atomizing nozzles, such as Monarch F80 series, Nos. 6.00, 7.00 and 8.00, or the equivalent in other brands.

So far, we have been careful *not* to mention the mist blower, and for good reasons. With herbicides it is the most fantastic plant killer yet known. We are afraid of it, because John Doe may have some choice vegetables and flowers across the road, and one knows what to expect if some of the fine spray drifts onto those plants. Actually, the mist blower in the 5 to 12 h.p. sizes has a place in brush control where the treatment area is isolated from useful plants and crops.

Where drift hazards can be avoided, the 2 h.p. Knapsack Mistblower can be a useful tool for spraying brush up to 30 feet in height, using 3 to 5 quarts of 2,4,5-T in a total of 2 to 4 gallons of finished spray concentrate per acre. A drop size range of 50 to 75 microns mass average diameter is best for most purposes. A good knapsack mist blower can treat 10 to 15 acres of brush per day. It is also useful for spot spraying and re-treatments. A good spray unit consists of two men (two blowers) to do the spraying and one man to refill and service the 2 sprayers.

The helicopter is being used successfully to treat many miles of rights-of-way along power lines using 5 to 6 quarts of 2,4,5-T in 4 to 5 gallons of No. 2 fuel oil per acre. Its use in some areas is prevented by the hazards involved. These hazards and methods of avoiding them are discussed in detail in Chapter IV. The helicopter should not be flown directly over power lines. Therefore, one object is to fly parallel to the line and throw a coase spray in from the edge of the right-of-way towards its center.

Public Relations Aspects. Maintain good public relations with the neighbors of your right-of way. We would not willfully damage a crop or ornamental plant, but we assume the responsibility if it should occur through improper handling. Injury can occur through volatility or particle drift. Avoid the chances of damage so as not to implicate your whole brush control program.

The streak of brown across the countryside is unsightly but it is of temporary duration in the conversion from brush to herbaceous weeds and grass. If we take some time to assure the interests concerned prior to spraying that this will occur; the criticism can be minimized. Many contract operators make a practice of obtaining permits to spray. That affords an opportunity to explain what is being done and what is expected. This creates a better feeling of understanding with everyone involved and it's just good public relations.

Wild Life. Quite frequently it is pointed out that herbicides reduce the food and cover of game birds and animals. Game management men agree that the presence of brush along rights-of-way for game cover has been over emphasized. The removal of tall growing woody species always results in other species succeeding. The herbaceous weeds and grasses which follow woody plant removal produce more food in forms of seeds and vegetation than was represented by the original woody plants. Also, some progress can be made towards merely knocking out all the brush directly underneath the power line wires including the tall trees on the right-of-way, and leaving the lower growth towards the edges for the benefit of wild life—such species as sumac, blueberry, huckleberry, and other berries, dogwood, viburnum, chockecherry, weeds, etc.

The removal of brush from cross country power and telephone lines creates additional acres of fringe area that is desirable for propagation of game birds.

Carlson (1953) points out that it becomes a matter of greater understanding and appreciation of the other fellow's viewpoint in maintaining good public relations. When the facts are known, there should be no difficulty in reaching a fair compromise. His paper also includes a good account of weed and brush control with chemicals.

Silvicides as a Forest Management Tool

A GREAT deal of material already given in this chapter is applicable to forest management, particularly the sections on chemicals, right-of-way spraying, and brush control. Some of the more specific problems and adaptations will be included below.

Selective chemicals make it possible to thin, release, and favor one species over another. The concentrated spray method of application, from the ground and from the air, will enable the forester to cover large and small areas quickly and cheaply. For example, as little as one to three quarts of 2,4,5-T ester can be used in 2 to 3 gallons of total finished spray per acre to effectively release conifers from aggressive, competing hardwoods. The use of silvicides in forestry is only in its infancy. A search of research worker lists, assignments, projects, and literature shows that less than two per cent of research on herbicides and silvicides has been dedicated to forestry in spite of the fact that this is potentially a very valuable, almost untouched field for development.

Silvicides have the following possible uses in forestry, too:

1. Control undesirable plant and tree species.
2. Release coniferous seedlings and trees (both natural and planted) that are being crowded out by undergrowth, hardwood sprouts and overstory.
3. Prepare brush areas for natural seeding and regeneration; and for planting.
4. Perform thinning operations:
    (a) within a single species, as the thinning of balsam fir seedling populations, or reducing seed production.
    (b) within mixed conifers, and
    (c) among mixed deciduous species
5. Control brush along trails and roadways through the forests.

Some needed project studies include:

1. The evaluation of promising new silvicide and herbicide materials, formulations, and mixtures containing one to three single and multiple purpose silvicides.

2. Determining the relative degree of susceptibility of different coniferous species and deciduous species to 2,4,5-T; 2,4-D; CMU; Erbon; Dalapon; 4(2,4-DB); 4(MCPB); Butyl ethanol ester of

3,4, dichlorophenoxy acetic acid; Butyl ethanol ester of 4-chlorophenoxy acetic acid; ACP903; CIPC; MCP; and other chemicals.

3. Evaluation of comparative brush treatments made (a) as one treatment only, (b) two treatments made in alternate years, and (c) treatments made every third year.

4. Evaluate treatments applied in (a) spring, (b) summer, and (c) fall, for the above tests.

5. The further development and testing of application equipment, both ground and aerial, including detailed information on cost, rate of application, drift, optimum drop size, dosage, and gallonage.

6. Releasing conifers under tall hardwood overstories, including means of proper utilization of hardwoods in the composition.

7. Evaluation of brush and shrub control under (a) normal, (b) clear cut, and (c) partial cut canopy when stump and foliar applications are made at various times during the year to release pines and hemlock.

8. Testing the value of hygroscopic compounds as glycols and carbowax; spreaders, extenders, and stickers (like aroclor, casein, and soybean and linseed oil) when added to silvicide mixtures.

9. Testing nutrient and physiological sprays:
   (a) Nutrients and fertilizers
   (b) 2,4,5-TP and other "blossom setting" hormones for stimulating "blossom setting" and seed and cone production, and for stimulating roots.
   (c) Blossom and seed-thinning chemicals.

10. Hazard studies should include information on drifting of fine droplets; avoiding high winds from the wrong direction; unsafe chemicals; improper application equipment and methods; and the effect of various chemicals and methods on fish and wild life.

11. Physiological studies; how, and to what extent silvicides enter and affect woody plants; and what is the significance and effect of:
   (a) Size of the molecule of the chemical as related to absorption or entrance into the leaf and plant.
   (b) Drop size; and effect of different numbers of drops per leaf or needle.
   (c) Position of drop on leaf: (1) upper versus lower surface, (2) nearness to veins, and (3) effect of thickness, permeability, and texture of leaf cuticle.
   (d) Other plant parts: Effect of separate treatments on leaves, petioles, veins, twigs, stems, and branches.

(e) Coverage: Treating given numbers and percentages of the leaves at top and bottom of the canopy or crowns to learn the relative effect of given degrees of coverage.

(f) Determine the effect of time and exposure on the quantity and proportion of the chemical that enters the leaves and plant system. Measure the effects of rains in removing the toxicant deposits.

(g) Determination of the relative influence on absorption of wet versus dry foliage (1) at time of treatment, and (2) following treatment.

(h) Trace the distribution of toxic chemicals throughout the plant, including roots. See Chapters II, III, and IV for information on application equipment and methods.

Aerial Application for Control of Brush and Trees In the Southwest

THE information below on control of brush and trees in the Southwest has been abstracted from a paper by Darrow (1955). The types of herbicides used currently in this area for woody plant control by aerial applications include principally the hormone-type or translocated chemicals such as 2,4-D, 2,4,5-T and 2,4,5-T propionic or silvex. Substituted urea compounds known as CMU or "karmex" and similar soil sterilants capable of translocation offer distinct possibilities for selective control of woody plants. Contact herbicides, such as the dinitro compounds, have limited use for situations in which forage improvement is the goal of brush control. These materials may, however, be advantageous in clearing and defoliation of total undesirable cover.

The applicator venturing into this field must, to be successful, possess or develop through training and experience two basic items: (1) knowledge of herbicides, what they are and do, and their limitations and potentialities; (2) knowledge of the factors governing the use or application of herbicides for plant control.

Factors influencing the use and application of herbicides may be treated under several topics: (1) plant factors, including species susceptibility; (2) soil factors; (3) climate factors; and (4) application and technique factors. All-important and regulated by the items listed are economic and social considerations, including legislative aspects and state laws restricting application.

Plant Factors

Species susceptibility to available herbicides is of primary consideration. The list of Southwestern species of woody plants for which aerial methods of control are recommended is short, but the acreages involved are relatively large. Current recommendations and suggested practices by species are as follows:

Recommendations

Mesquite

DISTRIBUTION AND ACREAGE: Arizona, New Mexico, Texas, and adjacent Oklahoma; 70,000,000 acres, including 35,000,000 acres of moderate to heavy infestation in Texas.

TREATMENT: Single application of emulsifiable low volatile esters of 2,4,5-T or silvex at 0.5 pound acid equivalent per acre in one gallon of diesel fuel and three gallons of water per acre; 45 to 90 days after leafing out in spring; May 15 to July 1 in North Texas area; late May and June in Arizona and New Mexico. Plants should be in full foliage under good growth conditions; spring rainfall normal.

Sand Sagebrush

DISTRIBUTION AND ACREAGE: Oklahoma and Texas; 7,000,000 acres.

TREATMENT: Single application of ester of 2,4-D at one pound acid equivalent per acre in three gallons of diesel fuel or one gallon of diesel oil and two gallons of water per acre, May 1 to June 10. Adequate rainfall and good growing conditions, and spraying shortly after a heavy rain increases effectiveness.

Sand Shinnery Oak

DISTRIBUTION AND ACREAGE: Oklahoma, Texas, and New Mexico; 15,000,000 acres of all species of shinnery oak.

TREATMENT: Three successive yearly applications of 2,4-D ester at 1 pound acid equivalent per acre yearly in 3 to 5 gallons of diesel fuel or in an emulsion of 2 to 4 gallons of water and one gallon of diesel fuel containing oil soluble emulsifier; from May 15 to June 15, under conditions similar to sand sagebrush.

Post and Blackjack Oaks

DISTRIBUTION AND ACREAGE: Oklahoma, Texas, Arkansas, Missouri, and adjacent southern states; 11,000,000 acres in Texas.

TREATMENT: *Mature woodland.* Two or more consecutive yearly applications of 2,4,5-T ester totalling three pounds acid equivalent per acre in 4 or 5 gallons of oil-water emulsion containing one gallon of diesel fuel; initial applications of 1.5 to 2 pounds per acre with re-treatment at 1 pound per acre.

Pole-sized stands. Stands with trees less than 6 inches in diameter and more than six feet in height may show effective reduction of canopy with single applications at two pounds per acre of 2,4,5-T ester.

Brushy Stands and Sprout growth. On bushy growth under 10 feet in height and on sprout growth three or more years of age, 2,4,5-T ester at 1 to 1.5 pounds per acre may be effective. Repeated applications at lighter rates may be necessary.

Recent tests have shown that silvex esters are equal to or more effective than 2,4,5-T esters in the initial treatment in woodland and sprout growth. The effectiveness of silvex esters in repeated applications has not been established.

Spraying should be done in early May to June 15 in Texas; June and early July in Oklahoma and northward. Plants should be in full foliage and in good growing condition following adequate spring moisture; best results have been obtained in Texas in the West Cross Timbers in woodland stands with a small percentage of associated species.

Whitebrush

DISTRIBUTION AND ACREAGE: Rio Grande Plain and Central Basin of Texas; localized in occurrence in an area of approximately 8 to 10 million acres.

TREATMENT: Single application of esters or amine form of MCP or low-volatile esters of 2,4-D/2,4,5-T at 1.5 pounds acid equivalent per acre in one gallon of diesel fuel and three gallons of water. In stands with a heavy overstory of mesquite, application at 8 gallons per acre may be necessary. A high degree of control from a single treatment is necessary for this species, as sprouts from dormant buds at the stem base grow rapidly if the plant is not completely killed. Control is favored by an early summer and fall following periods of favorable moisture for full growth. Good results have been obtained with October applications following early fall rains; early summer applications have not been consistent.

Control of Various Species by Aerial Methods

Pine-Hardwood Type. Preliminary studies of the effects of 2,4,5-T and silvex esters in pine-hardwood stands were initiated in 1954 in Nacogdoches and Newton counties in East Texas. Hardwood species included blackjack, post, and sandjack oaks, sweet gum, hickory and sassafras; pines included principally loblolly and shortleaf, with a limited amount of longleaf. Initial applications at rates of 1.5 and 2.5 pounds per acre showed little or no effect on conifer seedlings and seed trees.

Bottomland Hardwoods. Preliminary comparisons of the esters of 2,4,5-T, silvex, and 2,4-D/2,4,5-T in tests conducted in 1954 in the Trinity River bottom hardwood type have shown best initial defoliation with the combined esters of 2,4-D 2,4,5-T in stands containing elm, pecan, hackberry, willow, ash and water oak. Earlier work has indicated that an initial application of 2 pounds acid equivalent per acre in eight gallons of emulsion may give effective reduction in canopy and that two or more applications are needed for adequate control.

Shin Oak (Edwards Plateau). Three species of shin oak occur on the limestone soils of the Edwards Plateau. In applications made in two consecutive years at rates of one and two pounds per acre, silvex esters gave partial topkill but relatively poor rootkill of 3-year-old sprout growth. Treatments found desirable for the sand shinnery oak of Oklahoma and North Texas are not applicable on the species frequenting limestone soils.

Soil Factors

For most of the woody species studied thus far, effective results with hormone-type herbicides are obtained under conditions of adequate soil moisture for growth.

Some differences have been noted in the susceptibility of species to applications of herbicides on various sites. Mesquite plants growing on shallow ridge tops respond better than plants in valley bottoms. Post and blackjack oaks in deep valley sites are more easily controlled than plants on shallow ridge soils. However, in the oak woodland type, associated species such as elm, pecan, water oak, etc., which are usually more resistant to 2,4,5-T than oak, often occur extensively in the valley sites and thus reduce the general effectiveness of control.

Climatic Factors

Aerial applications of hormone-type herbicides should not be made in areas subjected to drought during the spring growing season. Spray applications made at or immediately prior to periods of precipitation have often given very satisfactory top and rootkills of mesquite and oak. In mesquite control tests, applications were usually less effective when excessive rainfall fell at irregular intervals and brought about the development of new immature leaves and terminal stem elongation at the time of treatment.

Character of weather at the time of application does not appear to have a significant influence on the control obtained with herbicide applications. Wind velocities upward of 15 miles per hour do not appear to affect control adversely. However, applications should not be made with wind velocities above 10 miles per hour to reduce the chances of drift to nearby susceptible crops.

Application Factors

CARRIERS. For control of most woody plants, oil-water emulsions appear to give equally effective results as oil solutions of comparable volumes. Diesel fuel is as effective and economical as other oils tested for mesquite and oak control.

SINGLE VERSUS REPEATED APPLICATIONS. Single applications have been effective in the control of sand sagebrush, mesquite, and whitebrush. Repeated applications are necessary in the control of sand shinnery oak, post and blackjack oaks, and possible for other woodland and timber types.

The tabulation below is at best intended only as a rough guide to the relative susceptibility of woody plants to three chemicals. It does not list the conifers, but it should be pointed out that they, particularly pines, spruce, and fir, are more resistant to 2,4,5-T than deciduous brush and trees.

References for Table 79 on page 486

* Conc. 4 lbs. acid per 100 gal. water
Best results June, July, Aug., early Sept.
Ten feet max. height controlled by chem.
** Conc. 16-20 lbs. acid per 100 gal. oil
Best results through dormant season
No limit to max. height controlled
*** Conc. 75-100 lbs. per 100 gal. water
Best results May, June, July, Aug., early Sept.
Ten feet max. height controlled by chem.
R—Resistant
M—Moderately resistant
S—Susceptible
?—Opinion divided

Table 79. Reaction of woody plants to herbicides

H. C. Ferguson

(Reprinted from the 1953 NEWCC Proceedings)

Plant Species Common Name Scientific Name	Water Carrier- Foliage Appl'n			Oil Carrier- Basal Appl'n	
	2,4-D- 2,4,5-T Comb'n*	2,4.5-T alone *	Am- mate ***	2,4-D- 2,4,5-T Comb'n*	2,4,5-T alone **
Ailanthus (Ailanthus glandulosa)	S	S	M	S	S
Arrow Wood (Viburnum acerifolium)	S	R	S		M
Ash (Fraxinus Spp.)	R	R	M	M ?	M
Basswood (Tilia americana)	R	M	M	R ?	M
Beech (Fagus grandifolia)	M	M	S	S	M ?
Birch (Betula Spp.)	S	S	S	S	S
Bramble (Rubus Spp.)	S	S	S	M	S
Buckeye (Aesculus Hippocastanum)	M	M	M	S	S ?
Cucumber Tree (Magnolia acuminata)	S	S	S	S	S
Elm (Ulmus Spp.)	S	M	S	S	S
Green Brier (Smilax retundifolia)	R	R	M ?	R	R
Gum, Black (Nyssa sylvatica)	M	S	S	M	M
Gum, Red (Liquidambar styraciflua)	S	S	S		S ?
Hawthorn (Crataegus Spp).	M	M	M ?	S	S ?
Hercules Club (Aralia spinosa)	S	S	S		S
Haw (Viburnum prunifolium)	M	M	M	S	S ?
Hickory (Carya Spp.)	M	S	M	M ?	S
Honey Locust (Gleditsia triacanthos)	M	S	M	S	M
Ironwood (Ostrya virginiana)	S	R	S	S	M
Laurel (Kalmia latifolia)	R	R	M	S	M
Maple, Sugar (Acer saccharum)	R	R	S	S	S
Maple, Red (Acer rubrum)	R	M	M	S	S
Oak, White (Quercus alba)	M	M	S	S	S
Oak, Red (Quercus borealais maxima)	M	M	S	S	S
Locust (Robinia pseudoacacia)	S	S	M	S	R
Paw Paw (Asimina triloba)	M	M	S		M
Persimmon (Diospyros virginiana)	R	R	M	M	M
Poplar (Populus Spp.)	S	S	S	S	S
Poison Ivy (Rhus toxicodendron)	S	S	S	M ?	S
Red Bud (Cercis canadensis)	M	M	S	S	M
Sassafras (Sassafras varifolium)	S	S	S	S	S
Spice Bush (Benzoin aestivale)	S	S	S		S
Sycamore (Platanus occidentalis)	S	S	S	S	M
Tulip Tree (Liriodendron tulipifera)	S	S	S	M ?	S
Willow (Salix Spp.)	S	S	S	S	S
Witch Hazel (Hamamelis virginiana)	S	S	S	S	S

Glossary of Common Herbicide Terms

Annual — A plant that lives only one year.

Aquatic — A plant that grows in water.

Aromatics — Compounds derived from the hydrocarbon benzene (C_6H_6).

Band Application — An application of spray or dust to a continuous restricted area such as in or along a crop row rather than over the entire field area.

Basal Treatment — A basal treatment is an application to the stems of plants at and just above the ground line.

Biennial — A plant that completes its growth in two years. The first year it produces leaves and stores food. The second year it produces fruits and seeds.

Blanket Application — An application of spray or dust over an entire area rather than only on rows, beds or middles.

Brush Control — Control of low-growing herbaceous and woody plants.

Carrier — The liquid or solid material added to a chemical compound to facilitate its storage, shipment or use in the field by means of increasing the bulk. (See also "diluent.")

Chlorosis — A yellowing of plant foliage which results from the halting of the development of the green coloring matter.

Compatible — Two compounds are said to be compatible when they can be mixed without affecting each other's properties.

Concentration — Refers to amounts of active material in a given volume of diluent. Recommendations and specifications for concentration of herbicides should be on the basis of pounds per unit volume of diluent.

Contact Herbicide — A herbicide that kills primarily by contact with plant tissue rather than as a result of translocation.

Defoliator or **Defoliant** — A compound which causes the leaves, or foliage, to drop from the plant.

Dicot (dicotyledon) — A plant that has two seed leaves or cotyledons. Generally includes the broadleaved plants. Leaves are not veined.

Diluent — Any liquid or solid material serving to dilute or carry an active ingredient.

Directed Application — An application of spray or dust to a restricted area such as a row, or bed at base of plants.

Emergence — The time when the first leaves of the crop plant come through the ground.

Emulsifying Agent — A material which facilitates the suspending of one liquid in another.

Emulsion — A mixture in which one liquid is suspended in minute globules in another liquid; for example, oil in water.

Epinasty — The twisting or curling of leaves and stems caused by uneven growth of cells. (A state of growing in leaves in which the upper surface grows faster than the lower surface and thus causes the leaf edges to curve down.)

Fibrous Root System — One composed of profusely branched roots with many lateral rootlets with no main or tap root development.

Growth Stages — 1. Tillering stage — when a plant produces additional shoots from a single crown, as in wheat.

2. Jointing stage — when the internodes of the stem are elongating.

3. Boot stage — when the seed head of a plant begins to emerge from the sheath — usually applied to the grain crops.

Hard Water — Water which contains certain minerals, usually calcium and magnesium sulfates, chlorides or carbonates in solution to the extent of causing a curd, or precipitate, rather than a lather, when soap is added.

Herbaceous — A more or less soft or succulent plant that does not develop woody tissue.

Herbicide — A chemical used for killing plants.

Leaf Blade — The expanding flat portion of a leaf.

Miscible — Two or more liquids which, when mixed together, form a uniform mix.

Monocot (monocotyledon) — Any seed plant having a single cotyledon or seed leaf. Includes corn and grass type plants. Leaves are mostly parallel veined.

Necrosis — The death of all or a part of the plant.

Perennial — A plant that continues to live from year to year. In many cases, in cold climates, the stem dies down but the root persists.

Phytotoxic — A substance poisonous to plants.

Post-Emergence Treatment — Any treatment made after the crop plants emerge.

Pre-Emergence Treatment — Any treatment made after a crop is planted but before it emerges.

1. Contact pre-emergence — an application made after weed emergence.

2. Residual pre-emergence — an application which kills weeds as the seed germinates or as they emerge either before or after the crop has emerged.

Pre-Planting Treatment — Any treatment made before the crop is planted.

Pubescent — Hairy stems or leaves.

Quick-Breaking Emulsion — An emulsion in which the components separate rapidly.

Rate and Dosage — These terms are synonymous. "Rate" is the preferred term. Rate usually refers to the amount of active ingredient material (such as 2,4-D acid equivalent) applied to a unit area (such as one acre) regardless of percentage of chemical in the carrier.

Rhizome — Underground root-like stem that sends out roots and leafy shoots.

Selective Herbicide — One which has more toxic action on weeds than on the cash crop in which the former are found. By this means weeds may oftentimes be controlled without damage to the cash crop.

Silvicide — A chemical or herbicide used for killing woody shrubs and trees.

Soft Water — Water which does not contain those minerals that prevent free lathering when soap is added.

Soil Sterilant — A material which renders the soil incapable of supporting plant growth. Sterilization may be temporary or relatively permanent.

Spray Drift — The movement of airborne spray particles from the spray nozzle outside the intended contact area.

Stem — That part of the plant above the ground which supports leaves, flowers, and fruit.

Stolon — Runners or slender stems that develop roots and shoots at the tip or nodes as in the strawberry plant.

Surfactant — A material which when used in pesticide formulations imparts emulsifiability, spreading, wetting, dispersibility or other surface-modifying properties.

Suspension — A liquid or gas in which very fine solid particles are dispersed, but not dissolved.

Synergism — Cooperative action of different agencies such that the total effect is greater than the sum of the two effects working independently.

Systemic Herbicide — A compound which is translocated readily within the plant and has an effect throughout the entire plant system.

Tap-Root System — One characterized by a primary or main root which grows vertically downward with few lateral fibrous rootlets.

Translocation — Transfer of food or other materials from one part to another in plants.

Vapor Drift — The movement of herbicidal vapors from the area of application to adjacent areas.

Vapor Pressure — That property which causes a chemical compound to evaporate

Vegetative Growth — Any above-ground parts of the plant, such as leaves and stems, not directly involved in reproduction.

Volatile — A compound is said to be volatile when it evaporates or vaporizes (changes from a liquid to a gas) at ordinary temperatures on exposure to the air.

Wetting Agent — A compound which when added to a spray solution causes it to spread over and wet plant surfaces more thoroughly.

Winter Annual — A plant that starts from seed germination in the fall, lives over winter and completes its growth, including seed production, the following season.

Woody Plants — Plants that develop woody tissue.

Pesticide — Any substance or mixture of substances intended for controlling insects, rodents, fungi, weeds and other forms of plant or animal life that may be declared a pest.

Table 80. This table is presented as a framework for future expansion of the section on chemicals and abbreviations.

Abbreviations Used	Chemicals
Alanap-1	N-1 naphthyl phthalamic acid
Allyl Al	Allyl alcohol
Ammate	Ammonium sulfamate
Aquasan	Mixture of petroleum fractions
BHC	Benzene hexachloride
C & C	Carbide and Carbon
CIPC	Isopropyl-N-(3-chloro-phenyl) carbamate
CMU	3-(p-chlorophenyl)-1, 1-dimethylurea
CP	Chloropicrin
Cyan Dust	Calcium cyanamid dust.
Dalapon	2,2-dichloropropionic acid
DN Em	Dinitro oil emulsions
DNOSAP	Dinitro ortho secondary amyl phenol
Endo	Disodium 3,6-endoxohexahydrophthalate
Gr Cyan	Granular calcium cyanamid
Iron S.	Ferrous sulfate
Karmex DW	3 (3,4-dichlorophenyl) 1,1 dimethylurea
KOCN	Potassium cyanate
M Br	Methyl bromide
MCP	2, methyl 4 chlorophenoxyacetic acid
MH	Maleic hydrazide
M Spirits	Mineral spirits
NaAs	Sodium arsenite
NaPCP	Sodium pentacholorophenate
Natrin	2,4,5-trichlorophenoxy-ethyl sulfate
Na EX	Sodium ethyl xanthate
$NH_2DNOSBP$	Alkanolamine salts of dinitro ortho secondary butyl phenol
$NH_4DNOSBP$	Ammonium salt of dinitro ortho secondary butyl phenol
NIX	Sodium isopropyl Xanthate
No. 2 F. oil	No. 2 Fuel Oil

Table 80. (Continued)

Abbreviations Used	Chemicals
Oktone	Octachlorocyclohexenone
PA	Phthalamic acid
PCP	Pentachlorophenol
PMA	Phenylmercuric acetate
PDB	Paradichlorobenzene
PDU	Phenyldimethyl urea
SES	2,4-dichlorophenoxyethyl sulfate
Sesin	2,4 dichlorophenoxyethyl benzoate
Silvex	2 (2,4,5-Trichlorophenoxy) propionic acid
S+N—869	Stauffer N-869
Stod Solv	Stoddard solvent oil
TCA	Trichloroacetic acid (salts)
TCBA	Trichlorobenzoic acid
2,4-DA	Alkanolamine salt of 2,4-D
2,4-DE	Ester form of 2,4-D
2,4-DLVE	Low volatile ester form of 2,4-D
2,4-D NaS	Sodium salt of 2,4-dichlorophenoxyacetic acid
2,4,5-TE	Ester form of 2,4,5-T
2,4,5-TLVE	Low volatile ester form of 2,4,5-T
Other Abbreviations	
Ea	Each
Ear	Early
Directed Spray	Directed application to base of crop
Dorm*	During Dormancy
G	Gallons
Post-E*	Post-emergence
Post-H*	Post-harvest
Pre-E*	Pre-emergence
Pre-H*	Pre-harvest
Spr*	Spring

* The designations of time refer to crops unless otherwise indicated in the table.

Literature Cited

Anonymous. 1955. Chemical Weed Control Recommendations. Miss. Agr. Expt. Sta., Cir. 195, 26 pp., illus.

Ahlgren, G. H. 1955. A cooperative weed control for New Jersey. Report of the Interdepartmental Committee on Weed Control. N. J. Agr. Expt. Sta.

Carlson, A. E. 1953. Weed and brush control with chemicals. *Arborist News* 18(1):2-7.

Darrow, R. A. 1955. Aerial applications of herbicides in the control of brush and woodland. Fourth Annual Texas Agr. Aviation Conf., pp. Fl-F5.

Fletcher, A. H. 1954 and 1955. Proceedings of 8th and 9th Annual Meeting, N. E. Weed Control Conf. (Public Health Section).

Iurka, H. H. 1956. Highways and herbicides. Proc. 10th Ann. Mtg. N. E. Weed Control Conf.

Long, E. J. 1955. New conservation domain. *Amer. Forests* 61(11):21.

McMahon, R. J. SHEBARWAC—The Roadside Revolution. A talk delivered to the American Road Builders Assoc., at Miami Beach, Florida. 1956.

Shaw, W. C. 1955. Recent advances in weed control in the United States. Brit. Weed Control Conf., Proc., 42 pp.

Snidor, H. J. 1940. Probable effect of weeds on fertility of soils. Ill. State Acad. Sci., Trans. 33:34-35.

Stahler, L. M. 1953. Chemical weed and brush control. *Farm Management* 2(4):35-50.

Wilson, H. K. 1944. Control of noxious plants. The Bot. Rev. X(5):279-326.

CHAPTER VII

AEROSOLS

Liquefied Gas Aerosols

Scope and Limitations

THE definition and description of gas aerosols has been presented in Chapters I and II, so that we may now begin with a discussion of their scope of use and limitations. The history of aerosol development is a lesson that should be learned and used for all potential pest control developments. Here is a method that at first appeared to be limited to indoor use of a few insecticides. From this small beginning, a large industry has developed. Sales of aerosol insecticides in 1956 amounted to 52 million units while non-insecticide products totaled an additional 240 million units.

The development of aerosol insecticides began with a few government workers (Goodhue, Sullivan, Smith, et al), who promptly published their results and discussed potentialities. Industry gradually became interested. The war and the military services . . . and DDT, gave great impetus to the development. This was followed by the participation of industry on a grand scale. That includes the expenditure of many millions of dollars for research and development: consumer education; advertising; dramatization of the method; and studies for uncovering every possible use, including that for perfumes, creams, paints, hair dressing, pharmaceuticals, foods, and many others. The development has been served by some of the best chemists and physicists, and up-to-date business management and modern packaging and distribution methods.

The aerosol dispenser has many potential uses, particularly in the field of chemical specialties for household use where convenience is of prime importance. It has also certain limitations. These include the apparent inability to apply atomized mixtures containing water or wettable powder, corrosion and container storage problems, compatibility and solubility limitations, the difficulty of handling pressurized liquid gases, and the cost of the propellant. It would be possible to refill some special type containers but the percentage of people who might refill them would be very small. Therefore, most of the cost of aerosols is for items other than for the material to be applied . . . for example can, valve and stem, cap, the propellant, solvent, packaging, shipping, distribution, and advertising. A 6-ounce can for 65 cents may contain only one to five cents worth of *use* chemical. This does not mean that there is a huge profit in aerosols. Far from it. The industry is a highly competitive one in which the profit percentage is not excessive. An aerosol representative put it this way, " . . . What difference does it make if a woman throws away 90 cents out of an aerosol dollar every few weeks for aerosol dispensed perfume or "hair fix"; or if a man purchases 3 cents worth of DDT or pyrethrum in a 95 cent aerosol bomb, if she or he can derive a compensating degree of convenience and comfort from the purchase."

A representative of a leading manufacturer of hand atomizers and compressed air sprayers stated the case for the hand sprayer, against the aerosol dispenser approximately as follows: a gallon (8 pints) of say 2 to 5 per cent DDT can be made for 25 to 35 cents or about 3 to 4 cents per pint. The insecticide mixture can be put out by the hand sprayer in any form: solution, emulsion, or suspension. When the tank is empty, any other insecticide or fungicide can be dispensed by refilling the same sprayer. Obviously both men's statements are relatively true for the conditions stated. On the other hand, each has its place.

The use of gas aerosols will continue in large volume, especially indoors and in the household, but will not be able to compete with mechanical methods in large scale field operations. What the manufacturers of mechanical insecticide application equipment fail to realize is that they have done practically no basic fundamental research to meet the potentialities. Moreover, they have not made any thorough study and analysis of the whole broad field of problems and potential uses for mechanical equipment to apply concentrated sprays. They have practically ignored consumer education. A business cannot expect to grow if it closes the door on proven new ideas. Greatest neglect has been in the field of small power, hand, and knapsack sprayers. A comprehensive program could increase the use and value of this equipment several fold as pointed out in Chapters II and III. It is conceivable that some of the people that have been doing aerosol research and manufacture could profitably enter and develop this field without too much changeover. A probable exception is the heavy power equipment category, which is not well suited for most aerosol industries. Otherwise, the possibilities exist for them in the case of small sprayers.

Insecticidal Aerosols

A LARGE number of reports and references were supplied by R. A. Fulton for use in preparing the following section on *insecticidal aerosols.* The sub-headings constitute a digest and summarization of the material furnished by him: Use during the war, Health hazards, Household aerosols, Greenhouse aerosols, and Field aerosols. One of the finest of the references used is a comprehensive report by Fulton and Rohwer (1954).

"The (aerosol) method was first tested in 1941 against flies and mosquitoes, and in 1943 U. S. Patent No. 2321 was issued to Goodhue and Sullivan, the inventors, and assigned to the Secretary of Agriculture. Licenses are issued royalty-free for the manufacture, use, and sale of products produced under the patent. . . .

"In order to produce an insecticidal liquefied gas aerosol, the insecticide is dissolved, usually with the aid of auxiliary solvents, in a low boiling liquid propellant (dichlorodifluoro-methane) held in a closed container. This propellant boils at —29.8°C. and its vapor pressure of 67.5 pounds per square inch gage at 20°C (68°F.) is sufficient to yield the contents of the receptacle or "aerosol" through a capillary tube reaching the bottom of the container. The liquid is discharged through a small orifice, varying in size from 0.013 to 0.024 inch diameter. As it is sprayed, a fine mist forms and the liquefied gas evaporates almost instantly, leaving the insecticide particles suspended in the air. . . ."

Use During the War. During World War II, the invention found extensive use by the armed forces in the form of one pound aerosol "bombs." The formula at first contained five per cent pyrethrum extract containing 20 per cent pyrethrins, two per cent sesame oil, and 93 per cent "Freon-12." It was later modified to contain two per cent pyrethrum extract, eight per cent sesame oil, and 90 per cent "Freon-12." Near the end of the war formula No. G-179 was developed which contained two per cent pyrethrum extract, three per cent DDT, five per cent, cyclohexanone, five per cent lubricating oil, and 85 per cent propellant. At the end of the war, aerosol dispensers found their way into civilian use. Most of the aerosols marketed during 1946 contained two per cent pyrethrum extract, three per cent DDT, five to seven per cent cyclohexanone or 10 to 12 per cent methylated naphthalene, and the balance propellant.

"Developments in the formulation, method of use and packaging of gas propelled insecticidal aerosols since the war have been rapid. Much of this has been stimulated by the discovery and availability of new insecticidal chemicals. Competition to produce less expensive devices has also contributed to developments, particularly in aerosols used to combat household pests.

Health Hazards. "The earlier work and development was directed to provide more convenient and effective means of controlling insects which annoy, attack or transmit diseases to man. The aerosol was intended to be released in closed spaces, and it was therefore necessary that the various ingredients be harmless to man. Prior to recommending any formulation for use in aerosol form, all the ingredients were appraised for toxicity to man. This policy has been continued up to the present for household aerosols. This means that materials not tested and cleared as to freedom from health hazard are not acceptable for use in household aerosols under the licensing procedure. This fundamental practice imposes certain limiting factors in the formulation of these household aerosols, restricting the propellant gases, the solvents and toxicants that may be used. Such restrictions are, however, not necessary for all types of insecticidal aerosols. There are certain uses, such as in greenhouses, where appropriate safeguards can be employed to protect the operator while applying and after using the insecticide. In these cases highly toxic materials may be used with reasonable safety. . . . "

Greenhouse Aerosols. Experimentation with gas-propelled aerosols to determine their possible usefulness in controlling various insects injuring plants grown in greenhouses began in 1941. It was quickly learned that a type of aerosol different from that for household use would be required. The ease with which practical procedures of use and application could be followed to safeguard the operator removed many of the restrictions on the type of formulations that could be safely used. One of the principal problems was the determination of the tolerance of the plants to the various ingredients. It was known that many of the important greenhouse pests such as thrips, the greenhouse leaf tier, azalea leaf-miner, rose midge, fungus gnats and the broad mite could be effectively controlled with DDT and that the persistency of the residues was beneficial. The amount of DDT required and its persistency on the plant when applied in aerosol form were easily appraised.

The problems of getting the desired amount of DDT in solution, holding it there under the various ranges of temperatures, and assuring effective release and dispersal were the principal ones in preparing formulations. Several solvents and several percentages of propellants thought suitable on the basis of their chemical and physical properties were subjected to tests and the presently used DDT greenhouse aerosol was developed which contains five per cent DDT, approximately 10 per cent methyl-naphthalene, three per cent acetone, and 82 per cent propellant.

The usefulness of this type of aerosol for control of greenhouse pests had hardly been accepted when so-called hexaethyl tetraphosphate, now known to have as its principal active component tetraethyl pyrophosphate, became available. Its effectiveness in controlling various plant pests was developed rapidly. It proved to be especially useful for the control of several aphids, spider mites common to greenhouses, the greenhouse whitefly, and certain mealybugs.

Tetraethyl pyrophosphate and associated ethyl phosphates are highly toxic to warm-blooded animals and are readily absorbed through the skin. In using these materials special precautions are required, including the use of mask and protective clothing. This presented no special problem as greenhouse operators have long been familiar with the use of highly toxic chemicals for insect control.

The need for special safeguards in applying tetraethyl pyrophosphate in aerosol form removed restrictions in reference to the toxicity of the propellant gas used with it and simplified the formulation of appropriate aerosols. Tetraethyl pyrophosphate and the commercial material referred to as hexaethyl tetraphosphate are readily soluble in methyl chloride. No auxiliary solvent is therefore required. Suitable and effective particle sizes could be produced by using 10 per cent of the commercial hexaethyl tetraphosphate which contained up to 20 per cent tetraethyl pyrophosphate (the active ingredient) and 90 per cent of the propellant, methyl chloride. Aerosols for greenhouses with this formula are now in common use. More recently experimental work has shown that by using the product now available containing up to 40 per cent of tetraethyl pyrophosphate, the ratio between the propellant gas, methyl chloride, and the non-volatiles can be 95:5.

The toxic nature of these aerosols for use in greenhouses introduced administrative problems in reference to licensing, labeling and distribution. These have all been met through cooperative effort. The pattern developed can no doubt be extended to other chemicals that are highly toxic to warm blooded animals but especially promising for the control of many common greenhouse pests. Parathion is one now receiving particular attention. This organic insecticidal material differs from any other insectide tested previously as it proved to be toxic toward a large number of unrelated insects which was not true with other organic insecticides. It has been found to be toxic toward all of the insects affected by DDT and tetraethyl pyrophosphate and in addition such diverse species as leaf roller, Surinam cock roaches, cyclamen mites, mealy bugs, and certain species of snails. Its residues possess a prolonged fumigating action which is toxic to aphids, spider mites, and cock roaches for several days to nearly a month. It has been tested against a wide range of plants growing in greenhouses and appears to be non-injurious except to a few varieties of roses and chrysanthemums. However, because information is at present inadequate in regard to the health hazard of this toxicant it has been approved only for use on ornamentals in greenhouses.

The combination of two highly toxic chemicals, tetraethyl pyrophosphate and methyl chloride, also presented problems of packaging and finding a type of container which could be used for shipment of the finished product. Specifications have been perfected and permits are being issued.

The development of these types of greenhouse aerosols has meant much to the greenhouse industry which annually produces roses valued at $400,000,000, which is approximately 40 per cent of the income from ornamental crops. Recent surveys have shown an improvement in quality of blossoms together with an increase in production of 10 to 30 per cent, depending on the condition of the greenhouse crops prior to treatment. The rapidity and ease with which effective insect control can be attained and the great saving in labor, a reduction from 28 man hours to 10 minutes—would seem to foretell even more general acceptance and wide scale use of greenhouse aerosols.

Field Aerosols. Gas propelled aerosols have also been developed for field use. Here, however, the progress has not been so marked. Effective formulations have been devised for use against certain truck crop pests, the most notable through the application of DDT for the control of pea aphid. With further work in this field in perfecting formulations, distributing devices, methods of servicing and shipping the product, we may expect considerable expansion in this method of applying insecticides. However, in more exact terms much of the field use of gas propellants falls in a category other than aerosol. Particle size studies show that these so-called aerosols are actually gas-propelled liquids. As is to be expected, best results can be secured when the toxicant remains in part on the plant and is distributed among the foliage, rather than into space. (Figure 153).

Livestock

CATTLE sprays in aerosol form contain pyrethrins, allethrin, Thanite, methoxychlor and other toxicants. A typical 12-ounce can will treat 50 to 100 cows, spraying about two seconds on each side of the animal. These chemicals may be used on dairy cows without danger of contaminating the milk.

The same aerosols may be used also for space spraying in a barn or other enclosed building to control such pests as houseflies, horn flies, stable flies, and mosquitoes. In such cases, a ten second spray usually is sufficient to treat about 1,000 cubic feet. Spraying, of course, should be repeated every day or two.

Use the Right Spray: DDT and lindane are used as active ingredients in many of the insect control sprays. When aerosol sprays are used directly on animals, however, the active ingredients should be checked carefully. DDT and lindane, for example, should not be used on dairy cattle because these chemicals tend to find their way into the milk. Because these same chemicals may also accumulate in the fat and tissues of beef cattle, sprays containing them should not be used on animals within 30 days of slaughter.

On the other hand, sprays containing either DDT or lindane are useful for treatment of hog pens, manure piles, chicken yards, and other areas where flies may breed.

Screw-worm Treatment: One of the more recent insecticidal aerosols is a preparation for control of screw-worm. A two or three second spray drives the medicine down deep into pockets and crevices of the wound to get a quick kill of screw-worm larvae. A single 12-ounce can, the manufacturer claims, treats 180 wounds, protects the cattle against re-infestation for five to seven days, and marks the wound with a color dye that makes it easy to locate treated areas. It is especially recommended for use after castrating, dehorning, or docking, and on wire cuts and similar injuries to protect against screw-worm infestation.

Another aerosol product is useful in combating ear-ticks, with treatment of cattle suggested before they are turned out on brushy grazing areas. One of the self spraying products recommended for use on horses not only repels bothersome flies but also is claimed to improve the animal's coat, making it glossy and easy to brush out.

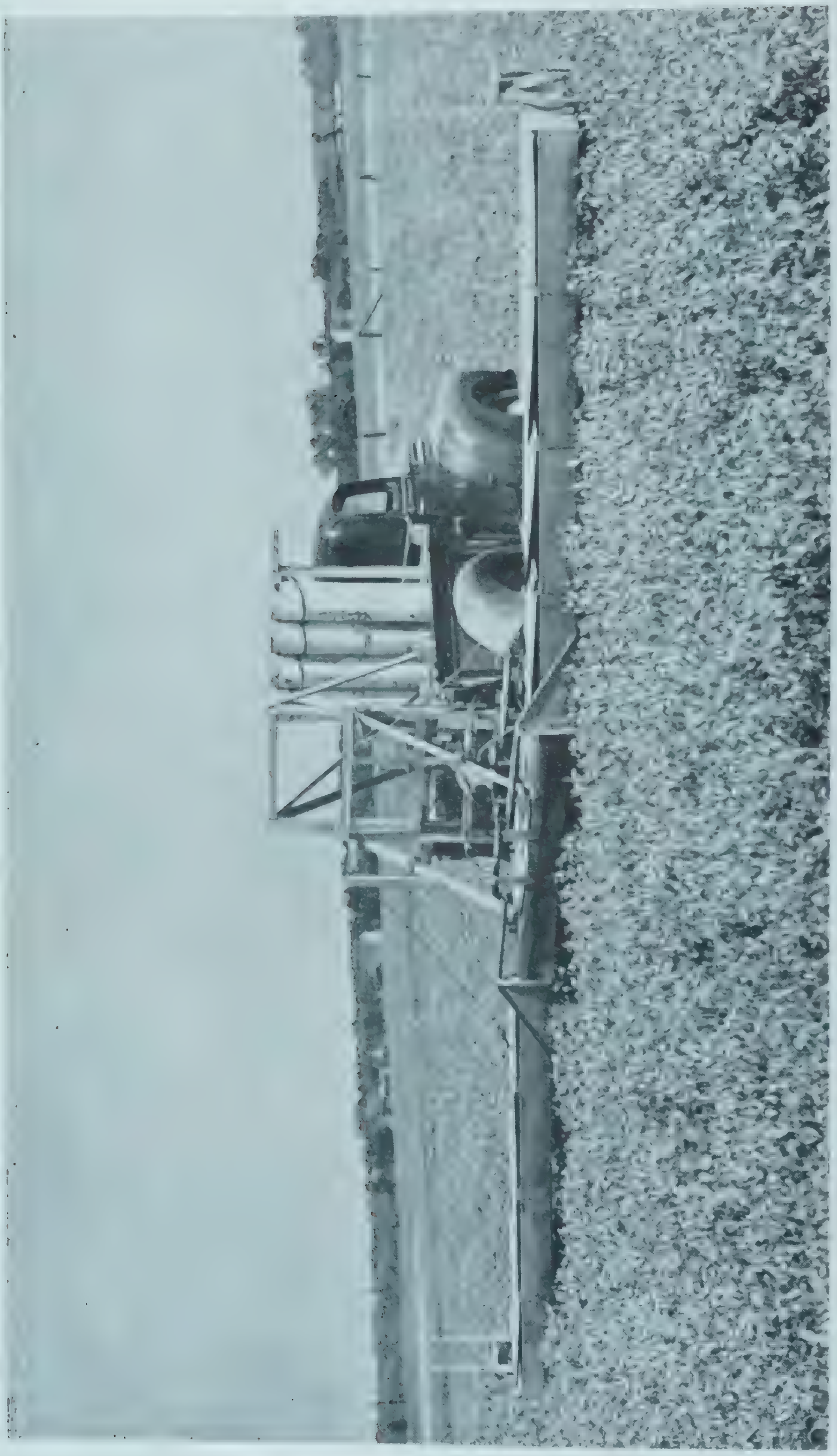


Figure 153. Applying liquefied gas aerosols containing DDT to field peas.

Courtesy University of Maryland, Department of Entomology.

For the poultry farmer, a vapor inhalant in the convenient, easy-to-use aerosol cans, helps relieve respiratory congestions in chickens caused by colds and bronchial infections. Sprayed in the poultry house according to directions, it aids in loosening accumulations of mucus in nostrils and throats.

Although not economical for use on commercial acreages, a wide variety of insecticides are available in aerosol form to control insect pests in both vegetable gardens and flower beds.

Thermal Aerosols

THERMAL generated aerosols appear as a spectacular white cloud. They are the true aerosols. The method recently had the benefit of large research staffs and expenditures and extensive promotion campaigns. There was a time during the war when it seemed as though many were rushing onto the band wagon to see who would lead the parade. For the author, this is a long story and not an altogether happy one. He felt in 1928, as today, that there is a restricted use for the thermal aerosols. They have several fundamental weaknesses such as the decomposition of many pesticides by intense heat, restrictions to the application of oil soluble chemicals in oil, inability to apply wettable powders, dependence on surface inversion of the air and on winds blowing in the direction of the target at 1 to 8 m.p.h., occasional fire hazard, and inability to deposit effective quantities of pesticide. Possible uses are in barns, greenhouses, warehouses, and under canopies in the field. They may also be used out-of-doors to drift insecticidal smoke clouds with the wind under suitable conditions to control flying insects like adult mosquitoes.

Field-Model Aerosol Machines

(Abstracted from papers and reports furnished by A. E. Yeomans)

"FIELD-model aerosol machines were developed during World War II. These machines release a foglike aerosol containing insecticide, which drifts with the wind over large areas (Yeomans, 1948). Under good conditions one of these machines can treat 25 acres per hour with one man as operator. Since aerosols remain airborne for considerable time, some flying insects like mosquitoes collect more of the insecticide on them than do stationary insects. Aerosol machines are best adapted to applying small quantities of insecticide over large areas, and for this reason a concentrated solution of insecticide is most suitable for use in them.

"One disadvantage of the aerosol method of applying insecticides out of doors is the requirement of suitable weather conditions. A surface inversion in the air is necessary to keep the aerosol close to the ground. The temperature near the ground should be 1°F. cooler than at 6 feet above to indicate a suitable surface inversion. This condition usually occurs on clear nights during the period between 1 hour after sunset and sunrise, and sometimes during the day when the ground is wet or cold. A light wind of from 1 to 8 m.p.h. and steady in direction is also necessary. The amount of deposit on foliage outdoors depends on the contour of the ground; the density, height, and types of foliage; the particle size of the aerosol; and the wind velocity and surface inversion. . . .

"There are three general types of field model aerosol machines—nozzle-type, thermal, and shattering.

Nozzle-Type Machines

GAS ATOMIZERS: "The gas atomizer is the most widely used field machine for producing aerosols. As in all atomizers, the size of the particles dispersed varies with the velocity of the gas and the surface tension of the liquid. The particle size increases rapidly with viscosity of the liquid if the amount to be broken up is large compared with the amount of gas used to break it up.

"The *cold-air atomizer,* such as a paint sprayer, has not been used to produce aerosols on a large scale, because it is difficult to overcome the viscosity of large quantities of liquid. Small quantities of oil solutions can be broken up into aerosols in this manner by adding low-viscosity and volatile solvents. When a DeVilbiss type WV air gun was used with a setting of 1 gallon per hour, a mixture of equal parts of deodorized kerosene and acetone produced particles of 10 microns mass median diameter and 30 microns maximum diameter.* An air pressure of 5 pounds per square inch was used, and the oil-set screw on the nozzle was open six turns and the air screw two turns. Cold-air atomizers are used for producing small quantities of fine sprays in insecticide test work, such as in Peet-Grady chambers, turntable tests, and some wind-tunnel tests. Aerosols produced by this method are heterogeneous in particle size. The minimum particle size that can be produced by this method is about 5 microns mass median diameter. This measurement does not allow for shrinkage due to evaporation after the particle is formed. Some of the new mist blowers use the air velocity to produce very fine sprays in the aerosol range, but they are not generally classified as aerosol machines.

---

* These drop sizes are larger than those for the true aerosols.

"The *hot-gas atomizer* is widely used for producing aerosols. The heat reduces the viscosity of oil solutions, and partially vaporizes the oil, which condenses into fine particles on contact with cold air. The gasoline-engine exhaust machine is one of this type on which considerable work was done during the war. In properly designed exhaust aerosol machines the oil-injection tube is exposed for several inches to the hot exhaust gases to lower the viscosity of the oil solution. For this reason the aerosol nozzle must be attached fairly close to the engine. The exhaust gas is increased to the maximum velocity by using a venturi tube and injecting the oil solution into the gas at the constriction of the venturi. The most satisfactory method of injecting the oil solution into the gas is through a large opening at low pressure. If the oil solution is injected into the hot gas through small openings, clogging and choking will result.

"In the gasoline-engine exhaust type of apparatus the particle size can be reduced by increasing the speed of the engine, and by decreasing the flow of liquid. The capacity of this type of generator depends on the size of the gasoline engine. The capacity, in gallons per hour, is roughly about one-third the brake-horse-power of the engine. The minimum constriction to use on the exhaust without building up too much back pressure is, in square inches, about 1/300 of the brake-horsepower.

"This method of producing aerosols is economical, and the cost of the equipment is negligible, if the motor is already on hand. When oil solutions are used, particle sizes from about 2 to 3 microns diameter up to mixtures of coarse and fine sprays can be produced. Some of the disadvantages are the difficulty in breaking up water solutions, and the possibility of thermal decomposition of the insecticide.

"This type of apparatus was used successfully during the war on jeep and aircraft engines. Since the war smaller engines down to 1½ hp. have been equipped with exhaust nozzles for indoor use or under canopies. For larger areas this method is well adapted for tractor engines.

"A method of atomizing a liquid by heating air and pumping it through a specially designed nozzle was perfected by a commercial firm. A 6½ hp. gasoline motor is used to drive a rotary-type air pump that delivers air at about 150 c.f.m. (Figure 154). The air passes through and is heated by a gasoline-burning combus-

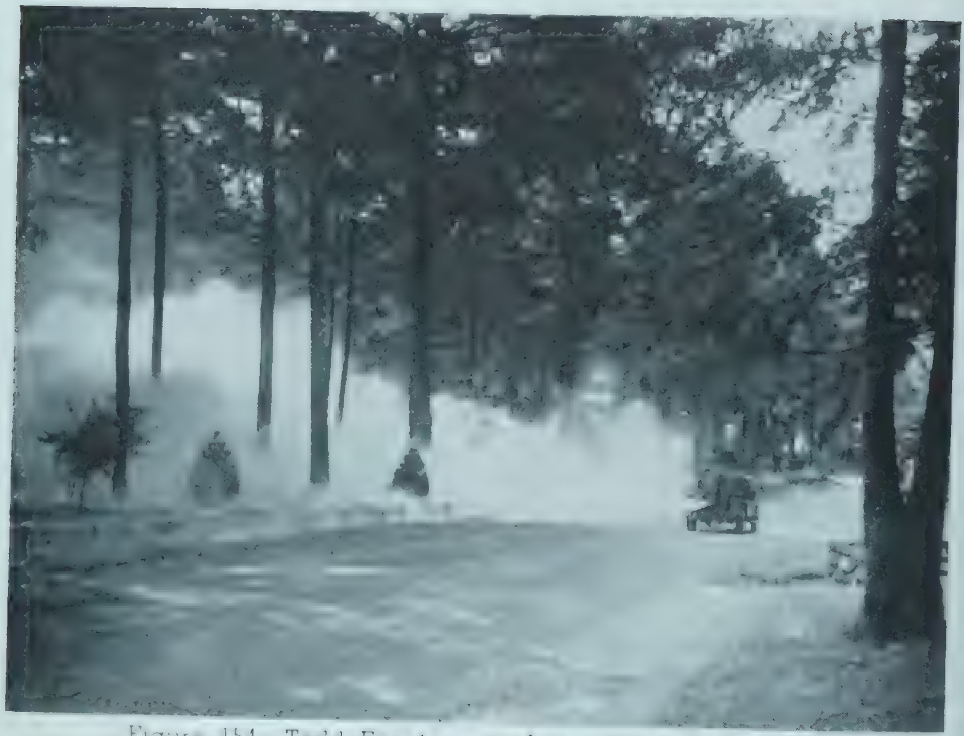


Figure 154. Todd Fog insecticide applicator in action.

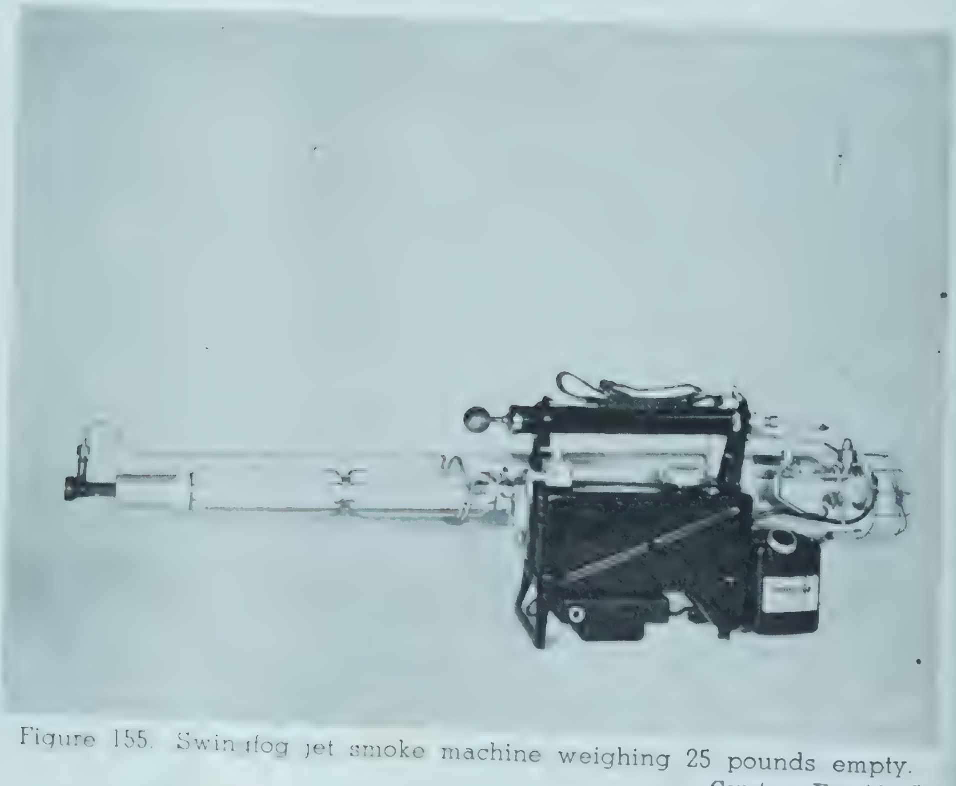


Figure 155. Swingfog jet smoke machine weighing 25 pounds empty.
Courtesy Fog-Air Co.

tion chamber fired by a constant spark and regulated to maintain a temperature of 900°F. The hot air then passes through special nozzles into which the insecticide solution is injected. A metering valve is used to regulate the flow of insecticide solution through the nozzle, and in this way the particle size is regulated. The insecticide pump, a centrifugal type, has capacity enough to supply 50-gallons per hour to the nozzles and to circulate 200 gallons per hour back to the insecticide tank to keep the solution agitated. In the specially designed nozzles the liquid and a small quantity of air are released at the base of the nozzle with a rotating motion. Most of the hot air comes in contact with and breaks up the liquid at the tip of the nozzle. This machine consumes about ½ gallon of gasoline per hour with heat off and 3 gallons per hour with the heat on."

The Fog-Air Company of 415 Lexington Avenue, New York, N. Y., distributes a 25-pound fogging unit known as the Swingfog that can be carried by hand (Figure 155). It delivers a fine, white, smoke-like aerosol.

Working on the pulse jet principle, it produces a stream of hot gas from an exhaust pipe into which the fluid is fed under pressure. This system is based on the fact that if air in a tube is subjected at any point to a sudden pressure rise, the result will be expressed in the form of a number of pressure waves running outwards through the mass. When a wave is formed, the pressure behind it drops down to a certain point and then builds up again to the next wave, the drop being proportional to the rise but not equal to it. Therefore, the maximum pressure will be followed by the minimum pressure, and if the original impulse is not repeated, the strength of the waves will weaken progressively until the effect has died away.

If, on the other hand, the sudden pressure rise is repeated continuously at the correct time, the effect will be to produce both maximum and minimum pressures in a series of regular pulsations in the system. Once these pulsations have been produced, they will continue even if the gas is given a further directional movement. A booklet of the manufacturing company describes the apparatus in detail.

"*Steam* has been used for some time to break up large quantities of oil. Columbia University, working in cooperation with the Bureau of Entomology and Plant Quarantine under OSRD funds, developed a pressure-shearing method in utilizing steam to break up oil. This method, called the Hochberg-La Mer method, consists in pumping a mixture of water and the insecticide solution through a coil which is heated in a conbustion chamber (LaMer and Hochberg). The heat converts the water to steam and lowers the viscosity of oil solutions. The steam pressure causes a shearing action which breaks up the insecticide solution as it issues from large jet openings. The combustion chamber is heated with either gasoline or fuel oil, and the temperature is regulated by a thermostat, which controls the amount of fuel pumped to the burner. A gasoline engine of about 1½ hp. is used to pump the water and insecticide solution, also to furnish air and fuel to the burner, and to furnish a constant spark from its magneto for the burner. The Army model E-12, used by the Bureau of Entomology and Plant Quarantine, is equipped with two plunger pumps, one to pump the water and the other the insecticide solution. Each pump delivers about 20 gallons per hour. The water and the insecticide solution are mixed before passing through the heater coils. This machine is equipped with two nozzles, set at a 60-degree angle, both 1 inch long with a ⅛-inch diameter opening. The particle size is controlled by setting the thermostat for temperatures between 300° and 600° F. The pressure developed by the steam ranges from 60 to 120 p.s.i. A relief valve is installed in the heater coil line to prevent excessive pressure.

"This machine is arranged so that water alone can be pumped through the heater coil until operating temperature is reached, and also to flush out the heater coils while cooling after use. This arrangement prevents waste of insecticide and reduces the danger of choking and clogging of the coils.

"When a mixture of 1 part of xylene in 4 parts of SAE 10W motor oil was used in a DDT solution, an average particle size of 10 microns was obtained at 600° F., 15 microns at 500°, 20 microns at 400°, and 30 microns at 300°. Less viscous oil solutions produced smaller particle sizes. Insecticide solutions used in this machine should have a higher boiling point than water; otherwise the particle size would be too small to be effective.

"The unit operates on the principle of keeping the insecticide solution in liquid form in order to produce effective particle sizes. It uses the nearest approach to the principle used in the aerosol bomb of any of the field machines, but was a total failure in orchards.

"Steam can also be used to break up insecticide solutions in the same way that air or other gases are used in atomizers. A machine to accomplish this is now available. It is similar to the thermal smoke generator or pressure-shearing machine, except that water alone goes through the heater coil and is converted into steam. The insecticide solution is by-passed around the heater and injected into the steam through a nozzle. A two-plunger pump is generally used—one for the water and one for the spray solution. This machine is equipped with a 1½ hp. gasoline engine, and has an output of 38 gallons per hour of insecticide solution and an equal quantity of water. The burner uses pressure-atomized fuel oil, which is ignited by an automatic spark from the engine magneto. There are two 50-gallon tanks, one with an agitator for the solution, and the other for water. The average fuel consumption of this machine is five gallons of fuel oil and one quart of gasoline per hour.

Pressure Nozzles. "Another method of producing aerosols is by exerting pressure on liquid. Pressure nozzles do not produce so fine a particle as the atomizers. Pressure nozzles, however, are generally simple, small, and inexpensive.

Rotating Disks: "Rotating disks are generally useful in breaking up very viscous materials. A commercial firm has designed and built aerosol machines with rotating disks, a small electrically driven one for indoor use, and a larger gasoline model for field use. These machines have several disks held together at the edge, and the insecticide solution is forced out from between them by centrifugal forces as they rotate at high speed. This method of using the disks limits their use to solutions, and viscosity influences particle size more than with the open type of disks. Constricted disks are reported to give finer particles than open ones.

"The latest field-model machine uses a 6½-hp. engine to rotate, by means of V belts, 21 disks eight inches in diameter at about 6500 r.p.m. A high-velocity blower with a capacity of about 4500 cubic feet per minute throws the aerosol out horizontally from the disks. The disks are mounted on a hollow shaft, through which the insecticide solution is drawn by the suction produced by the centrifugal force. A separate supply tank is used and must be mounted at least as high as the disks because the suction is reduced by a strainer located in the supply line. This machine will deliver up to about 250 gallons per hour, and the output can be controlled by a metering valve. It resembles a mist blower."

The size of particles issuing from the machine is a function of the output. The minimum particle size obtained with a solution of 2/5 xylene and 3/5 SAE 10W motor oil was about 40 microns mass median diameter. For smaller particles oil solutions of lower viscosity must be used or volatile solvents added. The base on which the machine is mounted allows a 20° tipback with a 360° rotation. The larger particles produced by this machine compared with other types do not limit its usefulness for field use except in cases where the maximum amount of penetration is required. The indoor electrically driven machine, with a rotation of about 17,000 r.p.m., produces smaller particles, with a mass median diameter of about 10 microns, when using fly sprays formulated with "Deobase."

Shattering Machine: Breaking up liquids by shattering has been used to only a limited extent to produce aerosols. Some tests have been made in which an insecticide was put into grenades and then exploded. The result did not appear practical because of the high cost of the explosive and the small quantities of insecticide dispensed. The method was used in woodlands by Potts in 1930.**

Aerosol Generator For 1½ HP Motors

YEOMANS and Bodenstein (1947) describe small gas engine attachments as follows: "Attachments using the exhaust of gasoline motors for producing aerosols were used on jeep and airplane engines for mosquito and fly control work by the American military forces during World War II. The particle size of aerosols produced by this method depends on the speed of the engine and on the rate of flow, viscosity, and other physical characteristics of the insecticide solution.

"An exhaust aerosol generator has been constructed to be used on a 1½ horsepower, 4-cycle gasoline motor. The cost of material and brazing, in addition to the motor, is estimated to be less than $10.00. The apparatus can be modified slightly for use on larger motors up to 20 h.p. This method of producing an aerosol is economical if the motor is already on hand.

"This apparatus can be used for killing flies and any other pests for which the aerosol bomb is used. The machine can be used in barns, greenhouses, warehouses, and houses, and under canopies in the field. It is not suitable for dispersing water suspensions unless small quantities are used, but most oil solutions can be used in the machine. It is not very effective out-of-doors.

"The carbon monoxide fumes build up with extended use of the machine in confined spaces, but for the usual time in applying insecticides the carbon monoxide is not objectionable.

"A Briggs and Stratton motor has been used with the governor

**Unpublished notes.

set for a speed of 2,500 r.p.m. The higher the speed the smaller the particle size.

"To break up the insecticide solution the oil is released into the exhaust gas as the gas escapes between the 3/16-inch diameter tube for the oil and the 1/4-inch diameter hole in the pipe cap. This opening is 0.0214 square inch, which is sufficient to allow the engine to be run with a back pressure of only about 3½ pounds per square inch.

"The flow of oil controls the particle size, and for ordinary fly sprays the flow should be about 4 liters per hour. This flow can be easily regulated by using a small opening in the oil line. On this machine the opening is 0.035 inch in diameter. When deodorized-kerosene standard fly sprays are used, this flow rate gives an average particle diameter of about 10 microns.

"The equipment required for this apparatus, in addition to the motor, is as follows: Three ½-inch pipe nipples—one 2½ inches, one 3½ inches, and one 5½ inches long; two ½-inch pipe caps; one ½-inch pipe tee; a piece of 3/16-inch (o.d.) copper tubing about 3 inches long; one half-union brass coupling with a ½-inch tube flare at one end and a ⅛-inch pipe thread at the other end; one ⅛-inch pipe valve; two ⅛-inch pipe fittings; and a discarded aerosol bomb."

Figure 156 is a cross section through the nozzle. The ½-inch pipe "B" is a continuation of the exhaust pipe from the engine. The ⅛-inch pipe above leads through a regulating valve to a discarded aerosol bomb which serves as a small insecticide solution tank.

Windborne Aerosols

WINDBORNE aerosols and fine sprays are those applied as a cloud and carried by the wind across the area to be treated. Insect control obtained by them is due mostly to the deposit, but individuals in flight are killed as well as those that come in contact with the deposit.

Machines for applying windborne aerosol sprays should not be confused with machines that project and drive sprays with a powerful air blast. The air blast machine can provide a more uniform deposit across a swath with either the smaller or the larger spray particles than can be obtained with the strictly windborne aerosols.

For best performance an aerosol cloud must be released under proper weather conditions, have uniform deposition in the selected

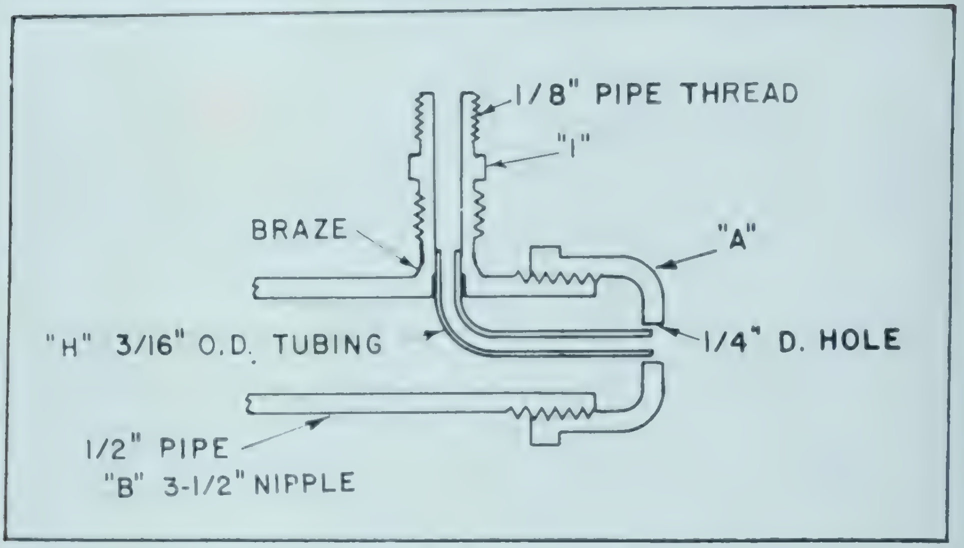

1/8" PIPE THREAD
"I"
BRAZE
"A"
"H" 3/16" O.D. TUBING
1/4" D. HOLE
1/2" PIPE
"B" 3-1/2" NIPPLE

Figure 156. Cross section through nozzle.

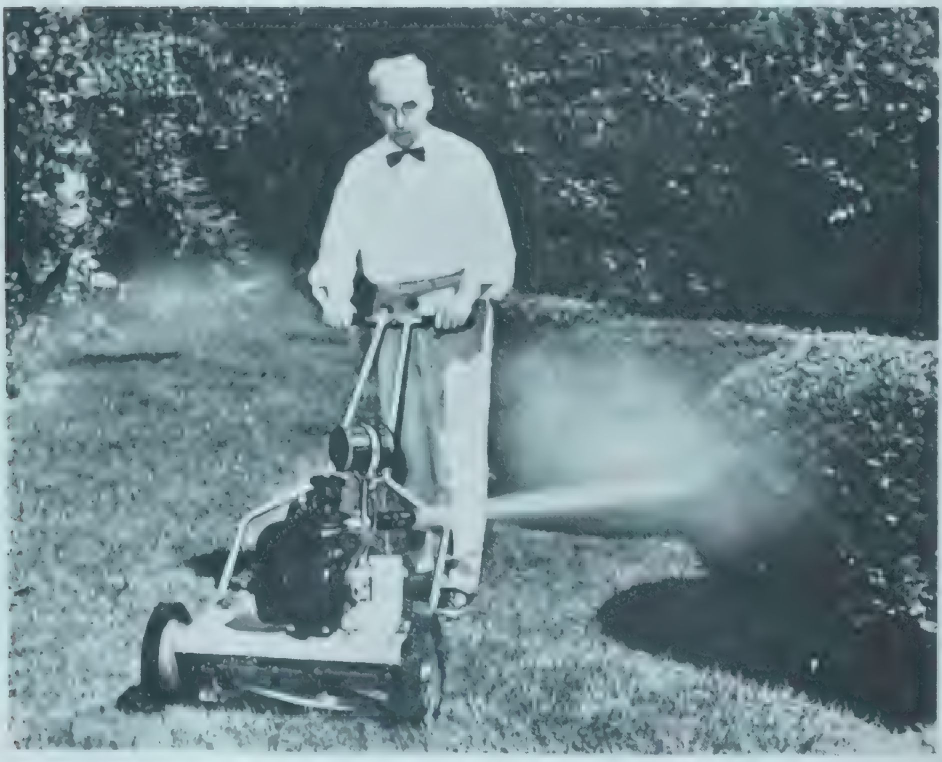


Figure 157. Fogging apparatus attached to a lawn mower.

swath width, be composed of particles of the right size, be of appropriate dosage and formulation, and be applied in the most economical manner. Surface inversion keeps the aerosol cloud close to the ground. It occurs only at night from 1 hour after sunset until sunrise, but occasionally exists all day when the ground is cooled by rain. When necessary to treat in the daytime without the surface inversion, a wind of 5 to 10 m.p.h. is beneficial.

Deposition of Fine Windborne Sprays and Aerosols

THE following information on windborne sprays is extracted from Yeomans (1950): "The deposit is heaviest nearest the point of release and decreases as the distance increases, because the larger particles settle out first.

"Aerosol particles moving with the wind deposit selectively on exposed vertical surfaces but settle uniformly on horizontal surfaces. The amount of deposit on the vertical surface depends on the size and shape of the object. Under similar conditions the deposit is much greater on objects of narrow width, such as pine needles, than on ones of greater width, such as maple leaves. The deposit on vertical surfaces becomes important when the aerosol is applied in winds stronger than 5 m.p.h., and on small tender foliage it is sometimes heavy enough to cause injury. When a large proportion of the foliage is exposed vertically, as in a vineyard, the increased deposition is especially important.

"Experience has shown that under the best conditions only 25 to 50 per cent of an aerosol containing particles of less than 50 microns mass median diameter* deposits in swaths up to 2000 feet, the major portion drifting beyond the area under treatment.

"The deposits of "aerosols"* of different particle size released in a 3-m.p.h. wind under good inversion conditions are given in Table 81. These deposits settled on an open field; the percentage would have been higher if the aerosol had been released through dense foliage.

Swath Width

"THE swath width is chosen first by the locations in the crop through which the machine can be taken with the least damage from the wheels. The minimum swath width is limited by the particle size requirements. A narrow swath requires large particles to settle out in the swath. Large particles sometimes cause foliage

---

*These drop sizes are larger than those for the true aerosols. The text here merely quotes the author of the paper.

Table 81. Effect of particle size on the percent of total insecticides depositing on 100-foot strips across a field when released in a 3-mile wind. (From Yeomans, 1950)

Distance from Release Front (feet)	Mass Median Diameter of Particles		
	75 microns	40 microns	25 microns
0-100	25.8	7.6	1.4
100-200	16.6	7.5	1.4
200-300	11.1	6.5	1.4
300-400	5.5	4.7	1.4
400-500	2.8	2.8	1.4
500-600	1.4	1.8	1.4
600-700	0.9	1.7	1.4
700-800	0.5	1.7	1.0
800-900	0.5	1.7	0.7

injury when oil solutions are used. The maximum swath width is limited by the dosage requirements. A wide swath requires a heavy output from the machines. Too heavy an output, even though the particle size is small, will cause foliage injury due to the heavy deposit near the source. The smaller particle sizes are less efficient in depositing within a limited area. For this reason it is best to select a swath as narrow as possible without causing too much damage from the wheels of the machine or foliage injury from the large particles.

Particle Size

"It is important to select "aerosols" of the proper particle size. The proper particle size depends on the swath width the "aerosol" is expected to cover, the wind velocity, and the amount of foliage penetration required.

"After the swath width has been chosen, the particle size that will give 25 to 50 per cent deposition of the "aerosol" at different velocities may be obtained from Table 82. These values were computed for an aerosol cloud released at an average height of 10 feet and under good inversion conditions. If penetration of dense foliage is required, the particle size indicated should be reduced by one-half.

"For example, 3 pounds of DDT in 3 gallons of solution released with a particle size of 40 microns* across a 100-foot front in a

---

*These drop sizes are larger than those for the true aerosols. The text here merely quotes the author of the paper.

Table 82. Optimum particle size, in microns mass median diameter, of aerosols for application at different swath widths. (Yeomans, 1950)

Swath Width (feet)	Wind Velocity in miles per hour							
	1	3	5	7*	9	11	13	15
50	55	98	—	—	—	—	—	—
100	40	70	92	—	—	—	—	—
200	29	50	65	77	90	98	—	—
300	24	40	53	63	70	79	88	92
400	21	35	46	55	62	68	73	79
500	18	33	41	49	55	61	66	70
600	17	29	37	45	50	55	60	65
700	15	27	35	41	47	51	57	60
800	14	25	33	39	43	48	53	57
900	13	24	31	36	40	47	51	55
1000	13	22	29	35	39	42	48	51
1200	12	21	27	32	36	39	43	46
1500	10	18	24	29	32	35	39	40

*Application at higher wind velocity is not recommended.

3-m.p.h. wind will leave a deposit of about one pound per acre across a 300-foot swath. If one pound of DDT in one gallon of solution is released across a 100-foot front and the particle size is raised to 70 microns,* the deposit will be one pound per acre across a 100-foot swath with the same wind.

"When the proper particle size has been selected, the aerosol machine should be set to produce this particle size according to the directions of the manufacturer.

"Sometimes temporary control of flying insects is desired. The optimum particle size for this type of treatment depends upon the kind of insect, and not upon the deposit. For adult yellow-fever mosquitoes the optimum particle size has been found to be 15 to 20 microns, and for house flies about 22 to 30 microns.

Dosage

"THE dosage depends on the deposit per acre of insecticide required to control the insect. It is measured by the amount applied per 100 feet of front, and varies with the swath width. Values are based on the premise that 25 per cent of the insecticide deposits in the first swath. Application to successive swaths results in overdrift, which increases the deposit by 10 to 20 per cent in each swath. In a large field the wastage due to overdrift is thus reduced to that from the last few swaths. For swaths less than 300 feet wide the dosage can be reduced by about 20 per cent, and for swaths 300 to 500 feet wide by about 10 per cent in each successive swath until the 50-per cent point is reached. This reduced dosage should then be repeated to the end of the plot.

The amount of insecticide required per 100 feet can be released by two methods. The total amount required on a front can be measured, then applied by moving the applicator back and forth across this front until the entire amount has been exhausted. The second method is to calibrate the output of the generator and then calculate the proper speed to move across the front to give the desired dosage. As an example, of the second method only, if it is desired to release two gallons of solution per 100 feet from an applicator with an output of 40 gallons per hour, the output per minute would be $\frac{2}{3}$ gallon. Since one mile per hour is equivalent to 88 feet per minute, the speed of movement would be

$$\frac{100}{88} \times \frac{2}{\frac{2}{3}} = 3.4 \text{ m.p.h.}$$

Formulations

“TO prevent rapid evaporation it is desirable that at least one-fourth of the aerosol solution be a nonvolatile liquid. Best results have been obtained with a very concentrated solution. A much used formula is 5 to 7.5 pounds of DDT dissolved in two gallons of benzene or xylene plus three gallons of SAE 10W motor oil or an agricultural oil. An agricultural oil is used where tender foliage is present. The amount of DDT that can be dissolved in the solvent depends on the temperature. Benzene is preferable to xylene.

“Benzene hexachloride, dinitro-orthocresol, pyrethrum, rotenone, toxaphene, chlordane, hexaethyl tetraphosphate, tetraethyl pyrophosphate, and nicotine have been similarly formulated. The last three insecticides are particularly noxious in aerosol form; an operator should therefore wear a proper gas mask when releasing them.

Method of Applying Aerosol

“THE initial impetus of the aerosol cloud, as it is emitted from the nozzle of the machine, should only place the cloud in the wind, and not deposit it on the foliage. The initial impetus is usually expended within 15 feet or less. It is preferable to point the nozzle low and back of the line of travel. The nozzle should never be pointed at foliage within the range of the initial impetus, because heavy deposit might cause burning. For treating low-growing crops the aerosol should be directed below the top of the surface inversion. When aerosols are applied in town, the nozzle should be pointed over the tops of parked cars."

Literature Cited

Fulton, R. A. 1956. Corrosion studies on aerosol containers. *Soap and Chem. Specialties* 32(2): 163.

Fulton, R. A. and S. A. Rohwer. 1954. Liquefied gas insecticidal aerosols. *Soap and San. Chem.* 30(2).

Yeomans, A. H. 1948. Field-model aerosol machines. U.S.D.A. Bur. Ent. and Plant Quar., ET-258, 8 pp., illus.

————. 1950. Directions for applying windborne aerosols. U.S.D.A. Bur. Ent. and Plant Quar., ET-282, 8 pp., illus.

————. and Bodenstein, W. G. 1947. An exhaust aerosol generator for 1½ horsepower motors. U.S.D.A. Bur. Ent. and Plant Quar., ET-238, 8 pp.

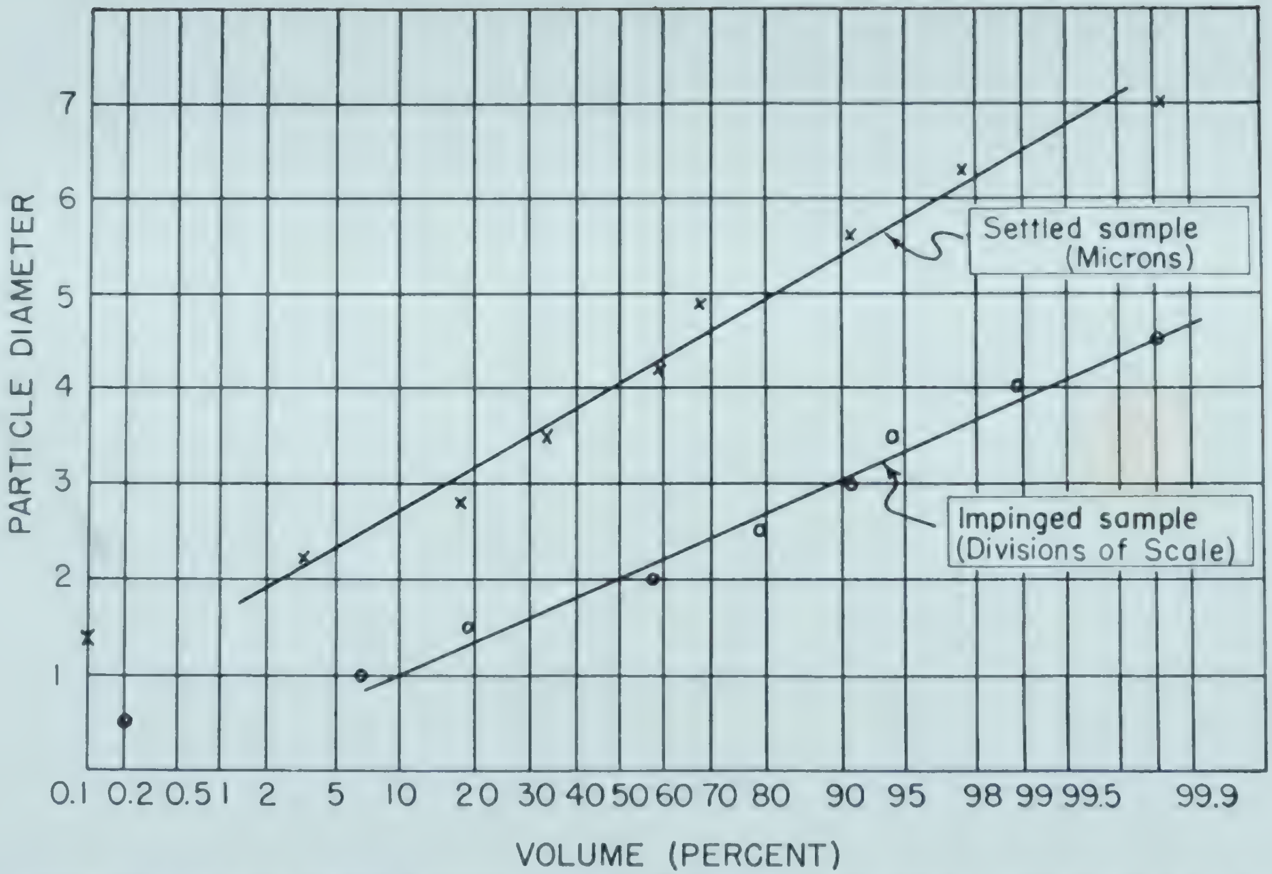


Figure 158. Percentage of the total volume of aerosol samples below each stated particle diameter impinged and settled on microscope slides. The mass median diameter is determined from the 50-percent point. The correction factor for spread has been applied to the data for the settled slide (from Table 84) but not to data for the impinged slide (Table 83).

CHAPTER VIII

APPENDIX

THE appendix contains much useful, condensed material that might not flow freely with the preceding text. This material includes methods of measuring particle size, sampling technic, some short-cut methods of determining deposit data, conversion tables, equivalents, and suggestions for course work.

Determining Particle Size of Aerosols and Fine Sprays

NO quick method is yet available. The best one is to deposit a spray sample on a glass slide (1 x 3 inches) and measure the small particles under a high-power microscope. Large drops may be more easily measured under a binocular microscope. An ocular micrometer grid scale is used to count the number of drops deposited per given area as per square millimeter, per square centimeter, etc. The linear micrometer is best for individual droplet measurement.*

Preparaton of Slides: Particles containing more than 25% of volatile materials which evaporate rapidly, usually cannot be measured directly. Their size can be estimated by measuring the craters they leave at the points of contact on slides coated with magnesium oxide or carbon soot. It is important to apply the right thickness of coating for the range of particle sizes anticipated. The relation between the actual particle diameter and the central circular spot (centrum) of the crater is illustrated later in an excerpt from the report of the University of Chicago Toxicity Laboratory.

Particles of relatively nonvolatile materials can be measured before they evaporate. To prevent excessive spreading, filming, or coalescence, the slide must be coated with an oleophobic substance that will cause the individual droplets to maintain their convexity to some degree. Three of the most satisfactory materials for this purpose are a 1 per cent alcoholic solution of mannitan monolaurate, 2 per cent magnesium stearate in benzene, or a silicon products manufactured as Dri film 9987 by General Electric Company.

Potts, S. F. Unpublished notes.

The slide is immersed in a cleaning solution, dried, immersed in the oleophobic-coating solution, and then after a few seconds lightly polished with a soft cloth. (Fumes from the Dri-film should not be breathed.) A slide coated with this material can be used for many samples, if it is washed with acetone after each use. When the droplets no longer remain circular, the slide should be recoated.

Deposition of Particles on Slides. A sample of an aerosol or spray cloud can be deposited on a slide by impingement or by settling, and measured according to the methods given below by Yeomans (1949).

"Deposition by impingement may be accomplished by moving the slide through an aerosol or spray cloud, or by moving the aerosol or spray cloud past a slide in fixed position. The velocity of movement in either case must be adjusted to the particle-size range expected. The velocity must be increased as the average particle size decreases. Since the deposition is in proportion to the particle size, compensation must be made for this factor. The Cascade and Micro Impactors developed in England, wherein an aerosol cloud is drawn through a series of orifices to vary the velocity, and impinged on a different slide at each orifice, is useful only with very small particles, mostly out of the range of insecticidal sprays.

"Deposition by settling should be limited to particle-size ranges below 20 microns in diameter. It may be accomplished by two means. An aerosol or spray cloud is released in an enclosure and allowed to settle onto slides placed on the floor or bottom. The cloud must be mixed to be uniform, and the aerosol or spray released in such a way as to prevent impingement on the sides or ceiling of the enclosure. The amount released should be small enough to prevent coalescing in the air or too heavy a deposit on the slide. Adequate time must be allowed for all the smaller particles to settle a distance equal to the height of the enclosure. Convection currents should be prevented as much as possible. A second and more rapid method is to draw the aerosol or spray cloud through an electrical precipitator in which slides have been placed. When the machine is turned on, all particles in the field are precipitated in a matter of seconds. Deposition by settling results in a slide representative of the entire range of particle sizes in the sample, with each size present in true proportion so that no adjustment or weighing is necessary.

Determination of Particle Size. "After the sample of aerosol or spray has been deposited on a slide, it is placed under a microscope and the individual particles are measured with an eyepiece micrometer. A mechanical stage on the microscope is necessary. The diameter as measured on the slide is then corrected for the amount of spread that has taken place, and the diameter of the original sphere is determined.

"At least 200 particles should be measured, according to DalaValle (1943). The more homogeneous the aerosol or spray, the fewer particles need be counted. All particles should be counted as they are seen in the field. An accurate method is to measure all particles from one edge of a slide to the other that pass through the micrometer scale as the slide is moved by the mechanical stage. Under some conditions of impingement, particles of the smaller size groups are congregated along the margin of the slide. Measurements in such areas should be avoided.

"It is sometimes useful to photograph the particles or to project them on a screen through a microscope. Better results have been obtained, however, by measuring the particles directly as seen in the microscope. It is often more convenient to measure in terms of the divisions of an eyepiece micrometer, and convert these divisions into microns after the median has been determined.

IMPINGED SLIDES.—"Samples may be collected by impingement on a coated slide by waving the slide through an aerosol or spray cloud, or by drawing the aerosol or spray past a slide in a fixed position, such as in a wind tunnel. The slide should be nearly perpendicular to the movement of the aerosol or spray. In either case the rate of deposition has been demonstrated to be in ratio to the square of the diameter. This rate of deposition was suggested by the Central Aerosol Laboratory of Columbia University and was based on Sell's law. To compensate for the decrease in the rate of deposition as the particle decreases in size, each diameter is multiplied by the number of particles of that size,* and expressed as the per cent of the total of such products. Representative data illustrating this method are given in Table 83.

"The accumulative percentages from the last column are plotted on the arithmetic probability scale in Figure 158. The 50 per cent point of the line so plotted is taken as the median of the particles as they appear on the slide. In this example the 50 per cent point has a value of two scale divisions, or 30 microns, as each division was predetermined to equal 15 microns.

"A correction factor must be determined for each slide. The original spherical droplet as it is impinged on the slide becomes a convex lens, and the extent of its spread from its original shape can be calculated by determining the focal length of the lens so formed. This method is described in Porton Report 2463 (May 6), a digest of which is appended (p. 521). In the example cited the correction factor is 0.40; therefore 30 microns X 0.40 gives a median particle diameter of 12.0 microns.

Settled Slides.—"The median diameter of the particles collected on a slide by gravitational settling or by electric precipitation is determined by calculating the volume of each particle. The diameter of the particles is measured in microns. The volume is determined by multiplying the cube of the corrected diameter by $\pi/6$, or 0.5236. The volume of the particles of each diameter is expressed as a percentage of the total volume. Representative data illustrating this method are given in Table 84. The accumulative percentages from Table 84. are also plotted on the arithmetic probability scale in Figure 158, and the median particle diameter is determined to be 4.05 microns.

Table 83. Representative count of aerosol particles impinged on microscope slides

Diameter (scale divisions)	Number of particles	Diameter times number	Per cent of total of column 3	Accumulative percentage
0.5	2	1	0.2	0.2
1.0	26	26	6.3	6.5
1.5	33	49.5	11.9	18.4
2.0	82	164	39.5	57.9
2.5	34	85	20.5	78.4
3.0	17	51	12.3	90.7
3.5	4	14	3.4	94.1
4.0	5	20	4.8	98.9
4.5	1	4.5	1.1	99.9
Total	204	415.0		

---

* The diameter is used in the first power only, since the particles impinge in ratio to D^2, but the mass median diameter is computed on the basis of their volume, which is in ratio to D^3; therefore, the number of particles is multiplied by D^2, D^3, or by D.

"Procedure for Measuring Spread Factor of Oil Droplets on Oleophobic Slides

(A digest of Porton Report No. 2463)

1. Use a compound high-power microscope.
2. Use a flat mirror.
3. Remove condenser.
4. Use outside light.
5. Focus on particle, and measure and record exact diameter.
6. Set reading on fine focus adjustment at zero.
7. Manipulate coarse focus adjustment and mirror until some distant object (window frame) is in as sharp a focus as possible, using the drop as a lens.
8. Then focus downward with fine focus adjustment until the drop is in clear focus.
9. The difference between the No. 6 reading of the fine focus adjustment (zero) and the No. 8 reading is the focal-length change.
10. Compute $\frac{f'}{2A} \; \frac{(\text{focal-length change})}{(\text{diameter of particle})}$

    Example: The diameter of a particle covering 4 divisions in an eyepiece micrometer (1 division = 15.4 microns) would be 4 X 15.4 microns, or 61.6 microns. With a focal-length change of 206 microns, the spread factor of the particle would be 206/61.6, or 3.3.

Table 84. A represenative count of aerosol particles settled on a microscope slide. (Volume $= \pi/6\ D^3 = 0.5236D^3$)

Diameter (microns)	Number of particles	Volume (microns^3)	Percent of total volume	Accumulative percentage
1.4	1	1	0.01	0.01
2.1	55	267	3.3	3.31
2.8	101	1161	14.5	17.81
3.5	50	1119	14.0	31.81
4.2	57	2211	27.7	59.51
4.9	11	677	8.5	68.01
5.6	20	1838	23.0	91.01
6.3	4	524	6.6	97.61
7.0	1	180	2.3	99.91
Totals	300	7978		

With this factor of 3.3, the correction factor (f'/2A) for this drop would be 0.40 (see below for spread-factor ratios).

Table 85. Spread-Factor Ratios.

$\frac{f'}{2A}$	Correction Factor	$\frac{f'}{2A}$	Correction Factor	$\frac{f'}{2A}$	Correction Factor
1.48	0.60	2.0	0.48	4.0	0.375
1.50	0.58	2.1	0.47	4.8	0.35
1.55	0.55	2.2	0.46	5.0	0.34
1.60	0.54	2.3	0.45	5.5	0.33
1.65	0.53	2.6	0.44	6.0	0.32
1.70	0.52	2.65	0.43	6.8	0.31
1.75	0.51	2.8	0.42	7.0	0.30
1.80	0.50	3.1	0.41	8.0	0.29
1.95	0.49	3.3	0.40	9.0	0.28
				10.0	0.27

Thin-Coated Carbon Slides

(Excerpt by W. R. Schmitz from University of Chicago Toxicity Laboratory, Informal Progress Report N.S. 2, May 15, 1945)

A METHOD has been described for the use of carbon-coated slides in estimation of drop size from sprays. In order to calibrate this procedure, which uses a thin film of carbon instead of magnesium oxide, we coated one half of the slide and left the other half plain.

The slides were washed carefully, rinsed in 1 per cent alcohol in water, and dried with a clean towel. A second slide was used to cover one half of the slide to be coated, and the two were passed through a small sooty gas flame. When the carbon deposit was thick enough to obscure rather heavy black type it was considered suitable. (Later comparison of slides coated by Lt. Wilson at NMRI indicates that our slides were somewhat thinner.) Slides prepared in this fashion have a carbon coating on one half and one half is clean. They were exposed to a graded series of clouds of the non-volatile dibutyl phthalate. The true drop diameters were determined from the lens diameters on the clean surface by determination of the focal length. The sizes of the central circular spots produced on the coated surfaces were also measured. The median diameters obtained on each type of surface were determined, and the results are given in the figures below.

Slide No.	True mass median diameter	Ratio drop diameter / diameter of centrum
1	4.48	0.71
2	4.63	0.89
3	9.09	0.81
4	10.5	0.95
5	17.9	0.70
6	18.8	0.74
7	20.8	0.67
8	49.0	0.67
9	51.5	0.54

There is ample evidence of marked variation in the ratio of drop diameter to centrum diameter of different slides, and the relation of this ratio to increasing diameter (MMD) is not regular. We have found no simple method, applicable to field operations, which will ensure uniformly thick coatings on all slides. Furthermore the best optical definition occurs at a thickness of carbon coating which is a function of the size of the drop. If the coating is very thin, it is possible to detect drops two microns in diameter, but larger drops are poorly defined; conversely, small drops are invisible on thick coatings. The diameter and appearance of the annulus surrounding the centrum appear to be very sensitive to variations in thickness of coating.

A Method of Determining Particle Size of Liquefied-Gas Aerosols

(Abstracted from Yeomans,* 1955)

A SATISFACTORY method of determining the particle size of liquefied-gas aerosols is to deposit a sample on a glass slide and measure the particles under a high-power microscope. The temperature of the formulation and dispenser has been made 80°F. to compare aerosol formulas, but at any temperature between 60° and 90° to determine the performance.

Deposition of Particles on Slide. The method of depositing the droplets on the slide depends on their size. For aerosols in which all the particles are less than 50 microns in diameter but the mass median diameter is more than about eight microns, an impactor can be used. This impactor consists of a 2,000-c.f.m. ventilating fan which draws the aerosol through a tube 20 inches in diameter and 60 inches long. The aerosol is released at the center of one end of this tube so that it is carried toward the fan at the other end. About 42 inches from the release point and 18 inches in front of the fan, the slide is revolved on a 4-inch radius at 400 r.p.m. This is done by means of a counter-balanced holder for the slide turned by a variable-speed stirrer motor (Central Scientific Co. No. 18805). The optimum air flow and the speed of revolving the slide in this impactor were determined from many tests but are not critical.

---

* An improved method developed by Yeomans in the Bureau of Entomology and Plant Quarantine. He is now with Biological Services of Agricultural Marketing Service, U.S.D.A.

The counterbalanced slide holder was constructed by cutting off two blades from a fan with blades eight inches in diameter and then flattening the remaining two blades. On the end of one blade a copper slide holder was soldered, three edges of which were bent 1/16 inch over the face of the slide, so that the slide could be pushed in easily, and so that the 1-inch open end of the holder faced the release point of the aerosol. The slide revolved counterclockwise so that its exposed face was in the direction of rotation. The outside 3-inch edge was located ahead of the bottom edge, making a 25° angle between the face of the slide and the 4-inch turning radius, in order to minimize sliding of the droplets due to centrifugal action. The fan blade was cut in the center to a depth of ½ inch and the forward piece bent down before the holder was soldered so that the slide had a clear path to collect particles. A weight was soldered on the end of the other fan blade to balance the slide holder and slide.

The time the slide is exposed in the aerosol is important. If there are too many particles on the slide, some will be deposited on top of others and give a false reading. It was found best to expose the slide long enough for about 0.3-0.5 gram to be released. This was accomplished by attaching the variable-speed motor with the revolving slide on a swivel and lowering it from a well in the side of the tube down into the stream of aerosol.

The swivel was constructed of ¼-inch pipe fastened to the inside of the 20-inch tube and serving as the axis. It was placed on the right side of the tube so that its center line was 3½-inches below the horizontal center line of the tube, 1 inch inside the wall of the tube, with one end 10½ inches from the fan. On this pipe axis a tee was attached loosely enough so that it could be turned; it was oiled periodically. On one side of this tee two pipes 4 inches long joined by a 90° elbow were attached. To the top pipe, which was parallel to the axis of the tube, the variable-speed motor was attached, and on the other side of the tee a handle for revolving it. This handle consisted of a pipe 2½ inches long, a 45° elbow, a pipe 12 inches long, a 90° elbow, and a pipe 30 inches long. The 30-inch pipe was also parallel to the axis of the 20-inch tube and could be used to move the variable-speed motor while holding the aerosol dispenser. A hole was cut into the side of the drum to allow the revolving slide to be withdrawn. A slot was also cut in which the handle moved. No cover is needed for satisfactory operation.

Determination of Particle Size: After the aerosol has been deposited on a slide, it is placed under a microscope, and the particles are measured with an eyepiece micrometer having 50 divisions, each division equal to 15.4 microns. A 100-power microscope is best for particles of aerosol size. A mechanical stage on the microscope is necessary. The diameter as measured on the slide is then corrected for the spread that has taken place so that the diameter of the original sphere can be determined.

At least 200 particles should be measured. All the particles from one edge of the slide to the other are counted as the slide is moved by the mechanical stage.

The accumulating percentages are plotted on an arithmetic probability scale (No. 3127, Codex Book Company, Inc.) The 50 per cent point of the line so plotted is taken as the median of the particles as they appear on the slide.

A correction factor must be determined for each slide. The spherical droplet as it impinges on the slide becomes a convex lens, and its spread from its original shape can be calculated by determining the focal length of this lens by the method described by May (1945).

DEPOSIT: In enclosures, about 95 per cent of an aerosol settles on the top of horizontal surfaces, and 5 per cent on the walls and ceilings. The amount depositing on horizontal surfaces depends on the concentration of the aerosol directly above that surface. Therefore, if the aerosol is evenly dispersed throughout a room, the deposit will be proportional to the distance of the surface from the ceiling. The deposit on walls and ceiling is mainly on small protrusions, such as fibers, on rough surfaces which catch the particles as they go by on air currents or by settling. Insects resting on the walls or ceiling will be struck by an occasional particle as it passes by. Surfaces colder than air temperature slightly attract very small particles.

A Photographic Method for Recording Size of Spray Drops

(From Davis, 1949)

IN analyzing the results of tests conducted with various types of equipment for spraying insecticides by airplane, we found evidence rather early that the degree of atomization was a governing factor in the lateral distribution of the deposit. A search of the literature indicated that the only method of determining a drop spectrum adequately was to measure and count the drops recovered in a sample of the spray. The requisite number of drops to be measured in an adequate sample increases tremendously as the drop size increases. Since we were dealing with sprays containing rather large drops, counting and measuring them with a microscope was exceedingly impractical. Therefore, we decided to avoid that method. Projected photographs appeared to offer the best possibilities. Since some sprays evaporate rapidly, we especially desired to develop a method in which the spray drops could be photographed in the field. The method evolved is essentially as described below.

Photographing the Drops: The samples are collected on microscope slides coated with an oleophobic film. In a typical test from 21 to 61 stations are prearranged at 10- or 20-foot intervals in a line perpendicular to the flight line, and three slides are placed at each station. Usually the falling spray covers only part of the line of stations. The spray is allowed to settle for 10 minutes after the plane has been flown over the sample line. The three slides from each station are then picked up and put in a clip to hold them parallel to each other. Each clip is placed in front of the lens of the camera with the middle slide in focus and the slides photographed. Only the middle third of each slide is recorded by this camera, which was developed especially for this work. The lens used most has a focal length of 4¾ inches but those of other focal lengths can be employed, depending on the magnification required The bellows is rigid, being a plywood box with shields inside to subdue reflections from the sides. The film is held in the back by a 4- by 5-inch film-pack adapter. This combination always gives the same magnification (about 4 times), since nothing is adjustable.

Beyond the lens is a circular target centered on the optical axis. The size and placing of this target should be such that its image just completely covers the negative at the lens stop used. The one referred to here is 5⅜ inches in diameter and is 21 inches from the lens. This arrangement gives negatives of high contrast, in which the background is transparent and the images of the drops are black circles or crescents. The exposures are made with the optical axis pointing directly at the sun. At f:64 1- or 2-second exposures are used for most panchromatic films on days of average brightness, and longer exposures under overcast conditions. At f:64 the depth of focus is sufficient to include the three slides used. Drops on the near slides will occasionally conceal a drop on a more distant slide, but the resulting error is negligible. With a somewhat larger "f" number this camera has been used to photograph as many as eight slides simultaneously.

If the spray consists of relatively small drops, having a mass median diameter of less than 100 microns, a 2-inch focal-length lens is substituted for the 4¾-inch lens, and a 2½-inch target at about 12 inches is substituted for the 5⅝-inch target at 21 inches. Only one slide is used, because at this magnification it is difficult to get depth of focus for more than one. One slide provides a sufficient sample, since the smaller drops are more uniform and fewer are needed. With this larger magnification also a smaller area is included in the photograph, but with smaller drops there are many more drops per unit area. It is possible that lenses of still shorter focal length could be used with very small drops, but we have not had occasion to measure drops where the mass median diameter was less than about 80 microns.

The apparatus described is usable when the *smallest drops* to be measured are *about 30 microns in diameter.* The mass median diameter is then usually greater than 100 microns. With the 2-inch focal-length lens the range is somewhat less than half the range with the 4¾-inch lens.

Measuring and Counting the Drops: The drops are measured and counted on a projection of the photographic negative. A cold-light photographic enlarger was altered so as to project upward from below onto a groundglass table top. The time required to count and measure the drops on the negative is usually too great to allow use of a conventional enlarger; hence the cold light was used. The over all magnification of camera and projector must be known. We determine this by photographing the jaws of a vernier caliper set at exactly one inch or other convenient length and then measuring the final projection of this opening. We use a magnification of 14.25, but this value has no particular merit over any other. The diameters of the drop images are measured, and the images classified

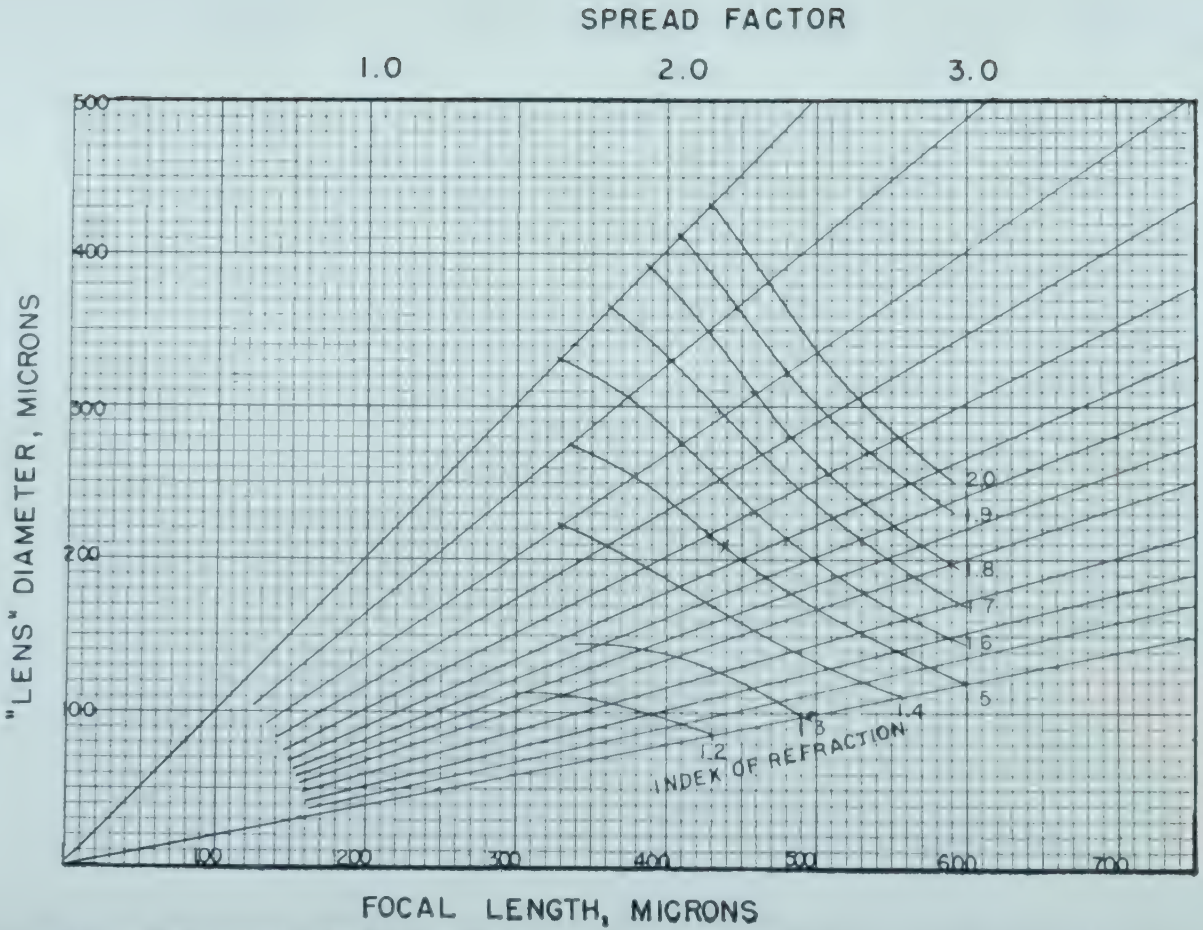


Figure 159. A chart for determining the spread factor when the index of refraction of the material and the ratio of focal length to the diameter of resting drops are known.

according to size. Each class has a diameter range of 1.0 mm., i.e., 0.5 mm. smaller and larger than the unit specified. These data are combined and totaled for all stations in the flight and sometimes for several flights, and the average-drop spectrum computed.

Determination of Spread Factor: In order to determine the actual size of the drops, it is necessary to know the spread factor, or the number of times larger the resting drops are than the spherical drops from which they resulted. This spread factor is determined by a method similar to one described by May (1945). This method involves two steps—(1) measurement by microscope of the diameters and focal lengths of a few representative drops, and (2) determination of the index of refraction of the material. It has been found advisable to tap the slide a few times with a pencil or fingernail before making microscope measurements to help the drops establish their equilibrium shape. The data are somewhat scattering; nevertheless, one is able to determine the average ratio, which is assumed to be a straight line with drops of the size ordinarily encountered. A vertical line upward from the point on the nomograph (Figure 159) where this straight line intersects the line of constant index refraction gives the value of the spread factor on the scale at the top.

Computations: The product of the spread factor and the overall magnification represents the number of times larger the images are than the original spherical drops. The micron size is found for each class by multiplying the class size by 1,000 and dividing by the product mentioned.

Each class size is cubed and multiplied by the number of drops in the class. These products are then expressed as percentages of the total and cumulated. The size corresponding to the 50 per cent cumulation is the mass median diameter. The sizes corresponding to 25 and 75 per cent cumulations indicate the range of size represented by the middle 50 per cent of the volume deposited.

In determining these various points we found it convenient to plot the cumulative volume per cent against the micron size on log-probability paper, as shown in Figure 160. On this curve the mass median diameter is seen to be 237 microns and the diameter range of the middle 50 per cent volume is 164 to 353 microns. In the class having the smallest diameter the images of the drops may be confused with those of dust particles, pollen, grains, etc. Therefore, data for this class are usually discarded. Although there may be a large number of these drops, they do not represent much volume,

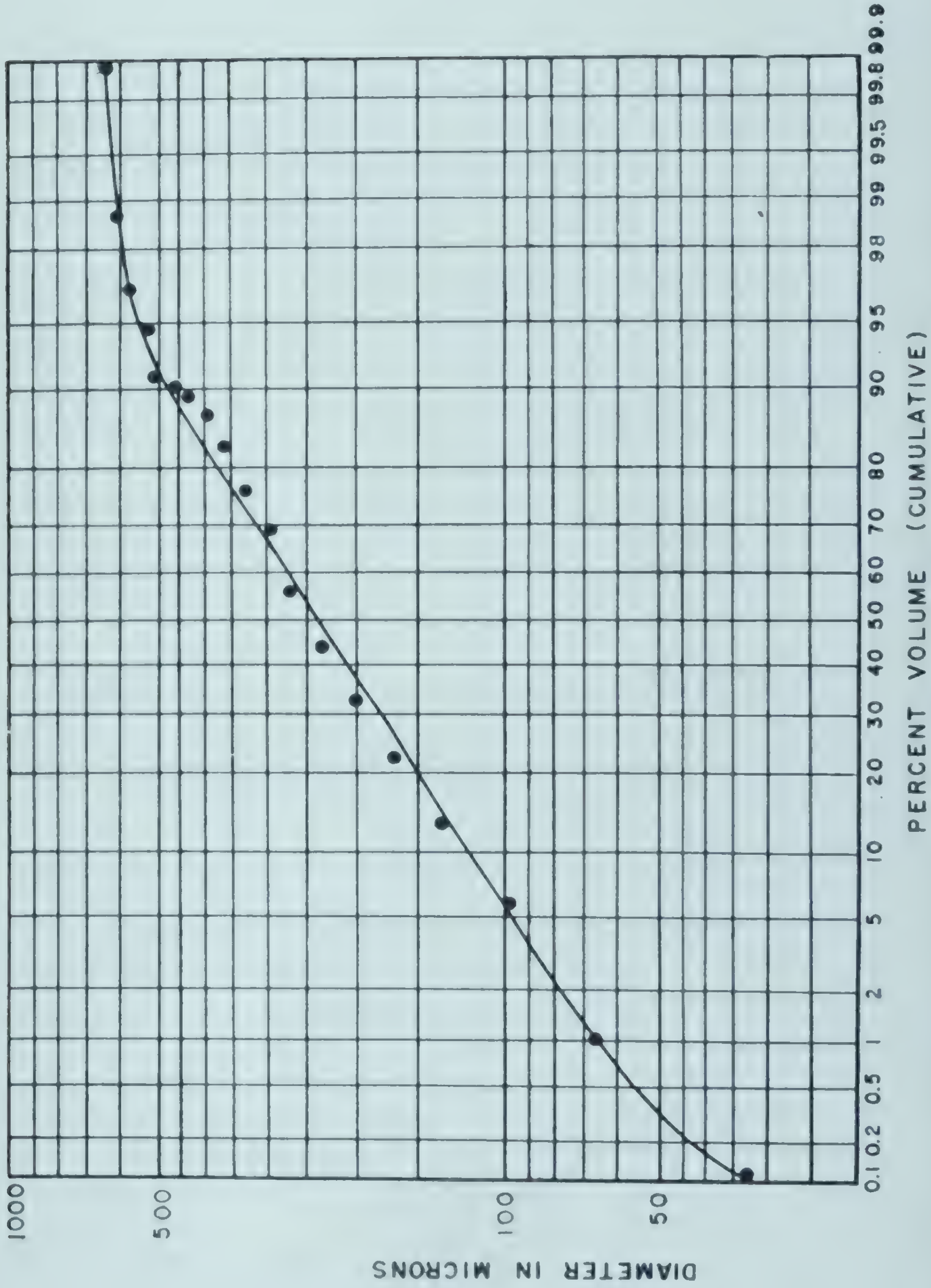


Figure 160. Cumulative per cent volume plotted against diameter of drops.

and the mass median diameter and the middle 50 per cent volume are affected only very slightly when they are discarded.

Advantages of the Photographic Method

(1) It provides a permanent record which can be measured when convenient.

(2) It is fairly rapid. Two workers can tabulate several thousand drops per hour.

(3) It is fairly clean, involving no smoke or coatings other than oleophobic material, which is simple to use, and is readily obtainable.

(4) It avoids errors due to evaporation from drop surfaces.

Determining the Depositing Efficiency of Sprays

A NUMBER of factors are concerned in the depositing efficiency of sprays. These include the distance of nozzle from the target, direction of the spray, drop size and velocity, included angle of spray, type of nozzle, nozzle output, etc. One method for measuring these factors is taken from the work of Yeoman and Rogers (1953) as follows: "We determine the percentage of spray material deposited by spraying against a large flat piece of absorbent paper, which is weighed before and after spraying under conditions such that the moisture content will not materially change. We use building paper cut into squares 30 inches on a side. For weighing it is rolled and inserted into a wire ring 5 inches in diameter suspended from a balance. For spraying it is fastened with four pinch clamps to a piece of flat corrugated cardboard and placed in the desired positions. We spray both horizontally and upward against the paper, wall, or ceiling to determine the maximum distance at which the spray will deposit satisfactorily. Usually at least 15 grams of liquid is sprayed in each test. Highly volatile liquids, as liquefied gases which completely volatilize before reaching the surface, are not included in computations for deposit. The effects of movement of the nozzle or cross air currents can be observed in this method."

Another method of spraying volatile and non-volatile liquids is described by Yeomans and Van Leeuwen (1954) as follows:

"**Test procedure:** All tests were made in a 2000-cubic foot room at 75° F. The air was saturated by spraying before each test to prevent loss of spray evaporation. . . .

"After determining particle size, we then determine the amount of deposit by applying a known quantity of spray against a metal wall surface and collecting the entire amount of runoff. There will be a natural runoff if the spray is applied to an already wet surface; otherwise it can be collected by use of a squeegee. We then compare the runoff with the amount sprayed and compute the per cent deposited. . . .

"For our studies we have been using a piece of galvanized sheet metal 12 feet long at the top and five feet wide at each end, with the lower edge tapering down to a width of 6½ feet at the center. At this lower edge of the sheet is a recessed trough, the ends of which are three feet off the floor and the center 1½ feet. At the lowest point the trough empties into a copper tube leading to a collector bottle. The trough is entirely behind the main spraying surface, so that it will not collect any spray except runoff. The spraying surface is bent back two inches above the trough, with a gradual smooth rounded bend so that the spray will not drip off sharp corners. A trough, one-half inch wide and one inch deep, handles the volume of liquid required for most nozzle outputs. For the runoff at the bottom a copper tube one-half inch in diameter is satisfactory. . . .

"Our test sprayer consists of a liquid container and nozzle. A six-volt solenoid valve releases the liquid at the nozzle. A quick-coupler refrigeration charging hose connects the nozzle to our container a stainless steel aircraft oxygen tank five inches in diameter and 22 inches long. This tank is held vertically, with the liquid draining out at the bottom and a combination liquid-filler and air-pressure valve at the top. Air or carbon dioxide is then supplied to the top of the liquid in this tank at any desired pressure up to 400 pounds per square inch.

"The nozzles are tested in a stationary position, since we have found that a stationary nozzle will give results comparable to those from a nozzle that is moved for hand spraying."

Other Provisions for Sampling Spray Patterns

ONE difficulty with the field sampling methods just described is that they do not catch all of the fine particles in the area exposed. For example, the photographic method of Davis does not intend to measure droplets smaller than about 30 microns in diameter and most other field methods merely catch the droplets that are big enough to deposit. To deposit and measure all droplets in a field sample at a given location it is necessary to trap the sample in the air and allow the droplets to settle out on a prepared slide.

This was accomplished by Potts and R. A. Spencer by equipping a box frame about 15 inches wide by 18 inches high with a spring and trigger mechanism designed to suddenly close all sides and the top with sliding curtains. While the sliding curtains are closing all sides a coated slide is exposed simultaneously to catch the settling drops. By this method a total sample can be obtained to cover the whole range of drop sizes. This method has the disadvantage of being time-consuming.

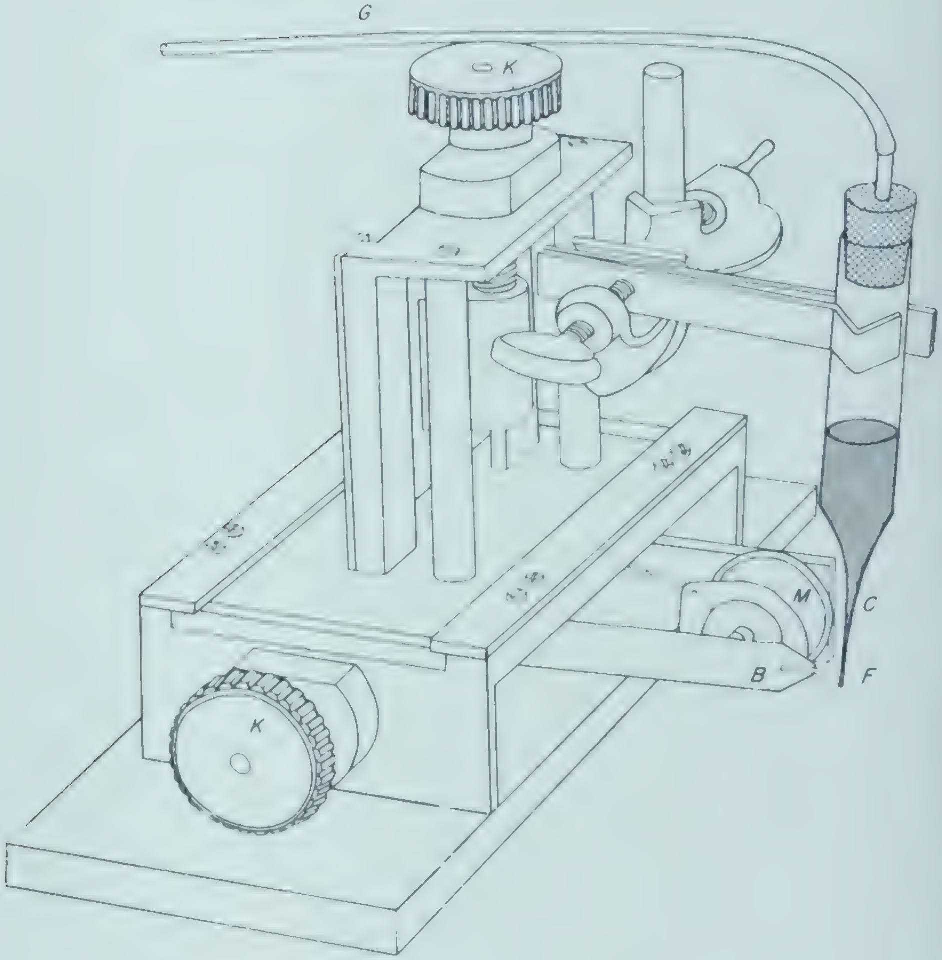
Samples from Conventional Nozzle Spraying Under Direct Pressure: For some time the author was plagued with the difficulty of obtaining a "total" settled sample from conventional nozzles under direct pressure of 10 to 400 p.s.i. The main difficulty was that the spray pile-up is so quick in settling chambers that no satisfactory pattern of separate droplets could be obtained on the slides. Spray sampling in the field gave the droplet deposit pattern under field conditions but did not register the droplets that were too small to deposit.

Several technics were used to obtain suitable samples. One consisted of releasing the spray downward from a nozzle placed near the top of a box, with dimensions about 6 x 6 x 6 feet. Coated slides are placed on the floor of the box. There is a second floor or horizontal partition two feet above this bottom floor which allows a small proportion of spray to pass through holes or slots cut in it. Samples of spray recovered on the slides below must first come through these slots or holes. Therefore, the total quantity reaching the slides is a function of the number and size of the holes or slots in the perforated partition. The slides may also be moved underneath the holes or slots. The length of time the nozzle sprays is controlled by a quick acting cut-off valve. Hence, the amount of spray reaching the bottom of the box (slides) is controlled by both the size and number of the upper floor openings and the shut-off valve timing. Sufficient time must be given for the smallest drops to settle.

Measuring Drop Size Indoors by the Settling Rate. The size of droplets can be measured according to the rate of fall, based on Stokes' law which gives the rate of fall of a small sphere in a viscous air or fluid. Under the action of gravity through a viscous medium spheres ultimately acquire a constant velocity.

$$V = \frac{2\,g\,a^2\,(d_1 - d_2)}{9\,n}$$

Where a is the radius of the sphere, d_1 and d_2 the densities of the sphere and the medium respectively, and n the coefficient of viscosity.



B Hacksaw blade

M Electromagnet

C Capillary

FF Finger

G Tube teed to water bubbler

K Slide control mechanism

Figure 161. Vibratory apparatus for producing uniform drops.

V will be in cm^3 per sec if g is in cm per sec^2, A in cm, d_1 and d_2 in a g per cm^3 and n in dyne-sec per cm^2 or poises. Advantage can be taken of the difference in rate of fall of droplets of different sizes to screen out or to recover droplets of given size with given time exposures. Air currents (or drift) can also be utilized to screen out the range of drop sizes within a spray pattern.

Stokes' law is of more value in helping measure the distance of drift of field sprays. The drift depends primarily on rate of fall (or time), height at which the spray is released, and the wind velocity.

For most practical purposes distance of drift (D) can be calculated with the following formula:

D = kh, where D = drift.

$$k = \frac{\text{speed of wind,}}{\text{rate of fall}} \text{ and}$$

$$h = \text{vertical distance of fall.}$$

If the drops are medium small to medium large the drift distance will be slightly less than indicated by the above formula, since the drops must travel the hypotenuse of an imaginary triangle.

Laboratory Apparatus for Producing Drops of Uniform Size

SEVERAL useful methods of obtaining drops of relatively uniform size have been used in the laboratory, though none of them may be entirely satisfactory. One of these methods is described by Davis (1951) as follows:

Vibratory Apparatus. "An apparatus for producing drops of uniform size has been developed in connection with a recent laboratory study of the behavior of individual drops within the size range normally encountered in insecticide sprays applied from aircraft. The drops are formed on and removed from a capillary by a vibrating finger at the rate of 60 drops per second. (Figure 161.)

Construction. "A simple 6-volt electromagnet (*M* in accompanying figure) is connected in a series with the secondary of an 8 volt doorbell transformer, the primary of which is fed from a variac off the 110-volt line. The finger (*F*) is made from a piece of wire from a paper clip (diameter 0.036 inch) about $\frac{1}{2}$ inch long, approximately half of which is flattened knifelike by hammering and filing. It is soldered to the end of a short length of hacksaw blade (*B*) with the flattened part projecting and with the flats at right angles to those of the blade. The other end of the blade is fastened to the base with a clamp so that the blade extends about 2½ inches and the free end bearing the finger is in front of the electromagnet. By projecting the blade more or less beyond the clamp it can be made to vibrate "in tune" with a 60-cycle current producing a 60 cycle-per-second vibration, the magnitude of which can be adjusted by the variac.

"A capillary (*C*) is drawn from a length of larger tubing (*T*), the undrawn part of which forms a reservoir for the liquid. The capillary is held vertically in front of the finger by an adjustable support with the tip of the capillary slightly below the level of the finger. Slide-control mechanisms (*K*) make possible a fairly fine adjustment in the position of the capillary relative to the finger. The magnitude of vibration is best when the finger almost touches the capillary at its nearest point of approach. Usually it is also necessary to apply a slight, controlled air pressure to the surface of the liquid within the reservoir. A water bubbler teed into the tube (*G*) is used to control this pressure. The water bubbler consists of a glass tube through which the excess air flow is allowed to escape under water. It has seldom been found necessary to apply a pressure of more than a few inches of water.

Operation. "Slow-motion movies of the apparatus in operation show that the following action takes place during one cycle (1/60 second) in which one drop is produced. Liquid is forced out of the capillary by the pressure behind it until a small drop begins to take shape. Early in its formation this drop rises on the outside of the capillary and makes a sort of torus, or ring, around it. It does not rise far, but takes up a stationary position, where it increases in size by the addition of material from the capillary. The correct vertical position at which to adjust the capillary is with the finger at the level of this torus. The finger approaches until it makes contact with the torus; then the drop begins to transfer to the finger. However, because of the high acceleration of the finger the material drops off as the finger recedes.

"When properly adjusted, uniform drops are produced at the rate of 60 per second, the succession of drops streaming in a single line as they leave the apparatus. The stream seldom falls directly downward but usually is projected outward. It is seen most easily when a light beam is played upon it. The drops are so nearly uniform in size that measurements under the microscope reveal no variation. When these drops are of oil, and are collected on a film of water, they will arrange themselves in perfectly aligned rows. This action would take place only if the drops were uniform. By using various sizes of capillaries and different pressures it has been found possible to make oil drops of any desired diameter between six and 140 microns. The machine has been used only on oil solution."

A Rotary Device to Develop Uniform Drops. A rotary device was developed by Rayner and Haliburton (1955) to produce uniform drops of liquids in the diameter range of 50 to 700 microns. A horizontally rotating blade detaches drops in a steady stream of regular trajectory, from a stabilized liquid mass fed under constant head through a stationary capillary. Its operation is described by Rayner and Haliburton, and performance characteristics with oil and aqueous test solutions are given. Drop size is calculated from the mass of drops emitted in a given interval at a known generation frequency. Variation in size of individual drops, electrostatic effects, and some uses for the machines are noted.

The unit has been used to deposit drops of known size on various sampling surfaces to evaluate or calibrate certain spray assessment technics, and to deliver metered amounts of solutions to specified containers or surfaces. Uniform spacing of drops was effected by wrapping test surfaces around a cylinder which was rotated and moved along its axis at controlled rates while intercepting a stream of drops. The helical trace thus "wound on" resulted in evenly spaced rows of drops when the surface was flattened out.

Distance Between Deposited Drops and the Percentage of Sprayed Surface Covered

Table 86 gives figures for one gallon per acre sprayed uniformly on an ideal "billiard table" surface. Although it has limitations since it is based on "monodisperse" sprays and ideally uniform deposition, and neglects the effect of coincidences of droplets, it does bring out the important point that the fraction of area covered increases as droplet size decreases. Ripper Courshee (1955), Daynes and Byass (1954) have pointed out that lime-sulfur sprays have a fungicidal influence around the speck of deposit of a droplet, the diameter of which is called biocidal range *d*. If area covered by the droplet on drying is called *S*, the postulate of the ratio between effective fungicidal cover and actual deposit cover is $(S + d)^2/S^2$, and is a maximum for a minimum drop size.

Table 86. Relation of droplet size, number of droplets, and areas covered by 1 gallon of liquid applied per acre in mono-disperse sprays on "billiard table."

Drop diameter microns	[a] No. of drops per cm.^{2}	[b] Mean distance apart in cm.	Fraction of area covered at contact angle = 90°
10	213,500	0.00216	0.266
20	26,700	0.00615	0.133
30	7,910	0.0112	0.0887
40	3,335	0.0173	0.0665
50	1,708	0.0242	0.0532
75	560	0.0425	0.0355
100	213.5	0.0685	0.0266
150	63.2	0.126	0.0177
200	26.7	0.193	0.01331
300	7.91	0.356	0.00887
400	3.33	0.551	0.00665
500	1.71	0.708	0.00532
750	0.56	1.34	0.00355
1000	0.213	2.16	0.00266

[a] 1 sq. cm = 100 sq. mm
[b] 1cm = 10 m m.

Determination of Spray Deposit

THE determination of pesticide deposits and residues is often a necessary means of evaluating spray equipment and formulations. Most pesticide deposit determinations have to be made by chemical analysis. Most methods of chemical analysis are time-consuming and often expensive. Many schemes are being contrived to short-cut the chemical analysis. Many factors influence the amount of residue found on treated forage, foliage and twigs and bark of trees. They include the stability of the pesticide, rainfall, dosage rate, method and uniformity of application, type of growth (height and density of stand), amount and uniformity of growth prior to and after treatment, weathering, harvesting conditions and methods (amount of leaves lost and moisture content), method of sampling, and length of time between treatment and sampling. Poos, Dobbins and Carter (1950) have described methods of sampling forage crops, and various other workers have used various sampling methods and adaptations of methods for residues on vegetables, fruits, and trees. Some of these determinations are made on a weight basis while others are on an area basis.

Dye Method for Determining Spray Deposition

FOR oil sprays and emulsions, an oil soluble dye such as Du Pont's "Oil Red" dye can be added to permit colorimetric measurement. Methylene blue can be used in water suspensions but is not as successful as for the dye-containing oil sprays. The dyes are used at various rates from 1/10 to 1/20 pound per gallon of mixture.

The colorimetric method described below was devised by R. H. Carter, Insecticide Division, B.E. & P.Q., U.S.D.A. for use by Roger F. Anderson, now of Duke University, who supplied the technique as given below:

Method of Analysis. Two 6-inch square glass plates or metal slides were used for collecting the spray deposits at each place from which a sample was desired After the spray had completely settled, each pair of plates was folded together so that the spray deposit was in between, placed in a box made to hold 24 such slides and then taken into the laboratory where the analysis was performed.

The plates of each pair were washed with 95 per cent ethyl alcohol by placing them, one at a time, in an 8-inch funnel and applying the alcohol by means of an atomizer. The pressure for operating the latter was obtained from a source of mechanically produced compressed air to which it was connected with a rubber tube. Through a second tube the alcohol was drawn up from a beaker on the table. The dye was washed off by going forth and back over the plates several times until no color remained. This dye alcohol flowed from the funnel into a 100 cc. graduate placed beneath. After rinsing the funnel, the volume of liquid in the graduate was brought up to 100 cc. with clean alcohol. The graduates used contained glass stoppers which made it possible to shake them vigorously, thereby insuring a thorough mixing of the dye. The sample was now ready to measure its light-transmitting property. (In more recent work, benzene instead of alcohol was used as the solvent. It was usually applied with a pipette or eye dropper.)

A "Type F" photometer as manufactured by the American Instrument Company, was used. The steps for adjusting the instrument and making the readings were as follows:

1. With the electric current turned off the photometer, the galvanometer light was set at zero.

2. The correct filter on the photometer was then placed in position. Number 53 was used for the "Oil Red" dyed solution and number 58 for the methylene blue.

3. Two clean test tubes containing uncolored alcohol were next placed in the machine, the dial reading placed at 100 and the galvanometer light again brought to zero by means of the adjusting rheostats on the photometer. The tubes should be marked so that they can always be kept in exactly the same position.

4. The right hand (facing the instrument) tube is now removed, emptied, rinsed with a few cc. of the solution from the unknown and then the unknown solution added. After wiping the tube again to be sure there are no finger prints etc. on the lower portion of the tube where the light strikes, it is then replaced in the instrument, and the reading made by adjusting the calibrated dial so that the galvanometer light is again brought to zero. The reading on the dial is then recorded. This value of the unknown is the per cent of light transmitted with respect to the transmission of light through the blank.

5. Either before or after the readings of the unknowns were made, a series of standards was made from a sample of the spray containing the dyes which were used in the test. This sample was then diluted so that the following concentrations were obtained: 1:10,000, 2:10,000, 4:10,000, 6:10,000, 8:10,000 and 10:10,000. The original sample was first diluted 1:100 and then samples of this dilution were used to make the final standards. Readings made from each of these standard solutions were then plotted over the quantity of DDT each should contain which, of course, depends on the concentration of the DDT in the spray mix. Different standards have to be used for each batch of spray unless the dye content etc. are very carefully controlled.

6. From this curve the quantity of DDT contained in each of the unknowns was read and then converted into any unit desired. The actual values obtained were per ½ square foot area, for this was the area of collecting surface used for the present work.

Davis and Elliott (1953) have developed a visual method of estimating aerial spray deposits on oil-sensitive cards. This method is very simple, quick and helpful even though it is not as accurate as ordinary chemical analysis. It is not intended for use as a visual assessment of deposits from very fine droplets of 5 to 40 microns. A digest of this method is given below:

In applying airplane sprays for insect control or for experimental purposes, it is essential to determine the dispersal and deposition of the spray material. This is usually accompished by placing indicating cards or recovery plates along lines laid at right angles to the line of flight of the aircraft to receive samples of the spray as it falls. For fast visual assessment, heavy pressed paper cards, known as jump cards, and sensitized paper have been used. These devices require the addition of a tracer or a chemical activator to the spray, and the results are often of questionable accuracy. For more accurate information, plates of glass or metal are used to capture the falling spray, thus permitting standard chemical or colorimetric analysis of deposits.

The chief disadvantages of these methods are the weight and fragility of the material, and the cost, handling hazards, and the need for laboratory facilities.

The final selection was a paper that before treatment is white, glossy, of medium weight and even texture, with a clay-bearing calender roll finish.[4] It is treated with an oil-soluble red dye in such a way that the greater part of the dye is left adhering to the surface.

When a spray droplet strikes the surface of the paper, it appears to dissolve and carry most of the dye to its perimeter. This results in a circular pinkish spot outlined by a dark ring of dye. Over a considerable range of drop sizes the ratio of the diameter of the ring to that of the droplet producing it is fairly constant, from 1:6 to 1:7 depending on characteristics of the spray used. Because this ratio is large, small droplets are readily visible, and because of its consistency, the method is usable for the rough determination of droplet sizes.

The indicated deposit may be expected to show some reduction due to evaporation. The amount of reduction will be somewhat proportional to the vapor pressure of the insecticide at the ambient temperature and to the time required for the spray to settle, and inversely proportional to the square of the drop size. The reduction is thought to be negligible with the oils used in most airplane sprays, but would be greater when more volatile solvents such as xylene or trichloroethylene are used.

---

[4] Some of the papers having the proper finish are Printflex Cover, Process Plate, and Richfold, which are available in various sizes and weights from Mead Paper Corp., Chillicothe, Ohio, and Kingsport, Tennessee.

These cards can be prepared by dipping the paper as rapidly as possible in a solution of one gram of Du Pont oil red dye in 200 ml. of acetone. They can be prepared also by applying the dye solution with a hand roller or brush. The acetone evaporates quickly, leaving the dye on the surface of the cards, which are then ready for use.

The size of the card is not critical, from 4 x 5 to 5 x 8 inches having been used. To keep the cards in the desired position or location, they may be fastened to anything convenient with thumb tacks, staples from a stapling machine, adhesive tape, or other means. After the cards have been exposed to falling spray, deposits can be evaluated visually to an accuracy of about 5 per cent by comparing them with known standards, i.e., previously prepared cards bearing known amounts of deposit.

Sets consisting of one card each representing the dosages 0.05, 0.10, 0.20, 0.50, 0.75, and 1.00 gallon per acre have been assembled into booklets for field use. Similar sets are kept unassembled for use in the laboratory; these cards are arranged in ascending order and the unknowns compared with them for assessment.

The chief advantages of this method of visual assessment are the ease of handling and the rapidity of evaluation. About 300 samples can be assessed per man hour in the laboratory. The method is ideal for control projects and with further refinement of standards may be sufficiently accurate for use in experimental spraying. Aerosols and very fine sprays of 30 microns diameter, or less, cannot be detected very well on the papers.

Determining Distribution of Lead Arsenate and Lead Acetate

HAMILTON and Smith (1925) developed a method of printing the deposit from leaves or other objects onto blotting paper. The method is made possible by the fact that lead salts, including lead arsenate, are soluble in sodium hydroxide. The dissolved lead can then be precipitated with hydrogen sulfide gas, sodium sulfide, or lime-sulfur solution. Colors of the lead sulfide thus precipitated range from light yellow through amber to dark brown.

In making the prints, white blotting paper is dipped into a 1 to 2 per cent solution of sodium hydroxide. Sprayed leaves are placed between two pieces of the moistened blotting paper, and the whole is then placed between several thicknesses of blotting paper. Then it is pressed in a letter press for 30 seconds. The blotting paper is next exposed to either H_2S, sodium sulfide or lime-sulfur solution. A brown precipitate of lead sulfide is formed which shows the distribution of lead as it occurred on the sprayed or dusted surface.

After the lead sulfide print is developed, the blotting paper is placed in running water and washed for 15 to 20 minutes to remove the sodium hydroxide, then is passed through a wringer, pressed to remove the water, and dried rapidly in moving air.

Method of Recording Copper Distribution on Sprayed Leaves

BLODGETT and Mader (1934) describe a method of making prints directly from leaves sprayed with Bordeaux mixture. Paper, such as blotting paper, is prepared by dipping it in an acidifying solution of potassium ferrocyanide in water. Two grams of potassium ferrocyanide in 2 to 5 per cent acetic acid was sufficient. The acid dissolves the copper. The potassium ferrocyanide in the paper reacts with the copper from the leaves to give a brown precipitate (cupric ferrocyanide). This precipitate produces a brown spot the size and shape of the Bordeaux spots on the leaf.

To make the prints the moistened paper is placed on a cotton pad covered with muslin. The leaves are arranged on the paper as desired, with the upper surface down. A second sheet of prepared paper is placed on top of the leaves if a print of both sides of the leaves is to be made. Another pad of cotton is then added. There are then, in order, a cotton pad, a prepared paper, a layer of leaves, another prepared paper, and another cotton pad.

The whole pile is then immediately placed in a press, such as an old letter press. Press slowly at first. Five to 10 minutes in the press is enough. After pressing, the paper is taken out and washed to remove the excess chemicals. Such prints may serve as a permanent record, and may be used as a basis for more accurate study of comparative coverage secured with different apparatus or on different parts of plants.

Mass and Measurements

THE material below consists of basic information on mass, measurements, conversion tables, equivalents, and handy charts selected for field and laboratory work. Much of it originally appeared in a paper by Nelson (1952). *Mass.* The basic units of the United States and British imperial avoirdupois systems differ in definition, but are equal for practical purposes. There are certain differences in terminology between the two systems that should be noted. A stone of the imperial system is 14 pounds. The system also uses 112 pounds as a hundredweight and 2,240 pounds as a ton. The hundredweight of the United States system is 100 pounds and 2,240 pounds is called a long ton. The latter unit is also the gross ton of maritime commerce, being originally based on an estimate of 12 pounds of container per 100 pounds of commodity.

The apothecaries and troy weigh systems should not be used in entomological work, and fortunately their use elsewhere is dwindling. Except for the grain, homonymous units in these systems and the avoirdupois system are not equal.

The metric ton is sometimes referred to as a millier or a tonneau.

Units of Mass

U. S. and imperial avoirdupois		Metric	
1 grain (gr.)	1/7000 lb.	64.798918 miligrams (mg).	64,698.918 micrograms (μg. or χ)
1 dram (dr.)	27.34375 gr.	1.7718454 grams (g. or gm.)	1,771.8454 mg.
1 ounce (oz.)	16 dr.	28.349527 g.	28,349,527 mg.
1 pound (lb.)	16 oz.	0.4535924277 kilogram (kg.)	453.5924277 g.
1 short ton	2000 lb.	0.90718486 metric ton	907.18486 kg.
1 long ton	2240 lb.	1.01604704 metric ton	1,016.04704 kg.
0.015432356 gr.		1 mg.	1000 μg.
0.5643833 dr.	15.432356 gr.	1 g.	1000 mg.
2.204622341 lb.	35.27396 oz.	1 kg.	1000 g.
1.1023112 short tons	0.9842064 long ton	1 metric ton	1000 kg.

Capacity — Liquid Measure

THE units of liquid measure have the same names in both the United States and the imperial systems. In no case, however, are they equal. The imperial gallon, quart, and pint are about 20 per cent larger, whereas the imperial fluid dram and fluid ounce are about 4 per cent smaller than the like-named United States units.

At 39.2° F. (4°C.) when it is at maximum density, a United States gallon of pure water weighs 8.345 pounds, an imperial gallon

Units of Capacity—Liquid Measure

United States		Imperial		Metric	
1 fluid dram (fl. dr.)	1/1024 gal.	1.0408 fl. dr.	—	3.69661 milliliters (ml.)	3,696.61 microliters (μ)
1 fluid ounce (fl. oz.)	8 fl. dr.	1.0408 fl. oz.	8.3264 fl. oz.	29.5729 ml.	29,572.9 μ
1 gill	4 fl. oz.	0.83268 gill	4.1634 fl. oz.	0.118292 liter (l.)	118.292 ml.
1 pint (pt.)	4 gills	.83268 pt.	3.33072 gills	.473167 l.	473.167 ml.
1 quart (qt.)	2 pt.	.83268 qt.	1.66536 pt.	.946333 l.	946.333 ml.
1 gallon (gal.)	4 qt.	.83268 gal.	3.33072 qt.	3.785332 l.	3,785.332 ml.
0.96075 fl. dr.	—	1 fl. dr.	1/1280 gal.	3.5515 ml.	3,551.5 μ.
.96075 fl. oz.	7.686 fl. dr.	1 fl. oz.	8 fl. dr.	28.412 ml.	28,412.0 μ.
1.20094 gills	4.80376 fl. oz.	1 gill	5 fl. oz.	0.14206 l.	142.06 ml.
1.20094 pt.	4.80376 gills	1 pt.	4 gills	.568245 l.	568.245 ml.
1.20094 qt.	2.40188 pt.	1 qt.	2 pt.	1.13649 l.	1,136.49 ml.
1.20094 gal.	4.80376 qt.	1 gal.	4 qt.	4.54596 l.	4,545.96 ml.
0.270518 fl. dr.	—	0.28157 fl. oz.	—	1 ml.	1000 μl.
1.05671 qt.	33.8147 fl. oz.	.8799 qt.	35.196 fl. oz.	1 l.	1000 ml.
264.178 gal.	1,056.71 qt.	219.97554 gal.	879.9 qt.	1 kiloliter (kl.)	1000 l.

10.022 pounds. At 62° F. (16.67°C.) these weights are 8.337 and 10 pounds. Twelve United States gallons (96 pints) of pure water weigh 100 pounds (very nearly) and 6 pints weigh 100 ounces (very nearly) at room temperature. The United States gallon is equal to 231 cubic inches and the imperial gallon to 277.418 cubic inches. There are 7.4805 United States gallons or 6.229 imperial gallons in one cubic foot. The United States gallon is the old English wine gallon no longer used in the British Empire.

Formerly in chemical and entomological literature the cubic centimeter (cc.) was commonly used as a misnomer for milliliter (ml.). Fortunately this is no longer such general practice. 1 milliliter = 1.000028 cubic centimeters; conversely, 1 cubic centimeter = 0.999972 milliliter. These units are related in the same sense as 231 cubic inches = 1 gallon. Occasionally the kiloliter is called a stere, but this word properly refers to the cubic meter.

Common Equivalents

A MEASURING cup and measuring spoons, the latter obtainable in nests of several sizes, are useful for making dilutions under practical conditions where great accuracy is not required. The values given here are also useful in transposing the precise measurements of the laboratory into commonly understood units when recommending an insecticide to door-yard gardeners.

In the absence of suitable scales for weighing, the use of these volumetric units for measuring powdered insecticides is a common practice. Tables of equivalents for such use have been published. With the more recently developed wettable powders, however, weight volume equivalents of wide application cannot be calculated because of differences in bulk volume and toxicant content of the numerous products. The expression "a pint is a pound" is exact for

1 teaspoonful = 4.8 mls.
3 teaspoonfuls = 1 tablespoonful
2 tablespoonfuls = 1 fluid ounce
16 tablespoonfuls]
8 fluid ounces] = 1 cup

16 tablespoonfuls
2 gills
½ pint
8 fluid ounces
237 milliliters
} = 1 cup

3 teaspoonfuls
½ fluid ounce
4 fluid drams
15 milliliters
= 1 tablespoonful

1 pint
16 fluid ounces
473 milliliters
= 2 cups

materials with a specific gravity of 0.96 and approximately true for water or for other materials with specific gravities near 1.0, but it is not true for powdered materials in general. It is suggested that those who wish to use volumetric measurements for powdered insecticidal material should determine the weight of such quantities as a tablespoonfull and a pint, and record these figures on the packages at hand. Weight dilution directions can then be transposed to these volumetric units and the equivalents given here employed.

Linear, Square, and Cubic Measure

Except for small differences in standards, the units of linear measure in the imperial system are the same as those used in the United States and the same conversion values may be used. It follows that this is likewise true for the units of area (square measure) and the units of volume (cubic measure).

Units of linear measure occasionally encountered are the surveyor's (or Gunter's) link and chain. The link is equal to 7.92 inches, and 100 links, equal to 66 feet, make one chain. The engineer's chain is 100 feet long, being divided into 1-foot links. The nautical or geographical mile is equal to 1 minute of arc on a great circle

Units of Length

United States and imperial		Metric	
1 inch (in.)		2.54 centimeters (cm.)	25.4 mm.
1 foot (ft.)	12 in.	3.048 decimeters (dm.)	30.48 cm.
1 yard (yd.)	3 ft.	0.9144 meter (m.)	9.144 dm.
1 rod (rd.)	10.5 ft.	.502921 dekameter (dkm.)	5.02921 m.
1 mile	5,280 ft.	1.6093472 kilometers (km.)	1,669.3472 m.
0.03937 in.	—	1 millimeter (mm.)	1000 microns (μ)
.3937 in.	—	1 cm.	10 mm.
.3280833 ft.	3.937 in.	1 dm.	10 cm.
1.0936111 yd.	39.37 in.	1 m.	10 dm.
1.988348 rd.	10.936111 yd.	1 dkm.	10 m.
0.6213699 mile	198.8384 rd.	1 km.	1000 m.

Units of Area

United States and imperial		Metric	
1 square inch (sq. in.)	—	6.451626 square centimeters (cm.^{2})	645.1626 square millimeters (mm.^{2})
1 square foot (sq. ft.)	144 sq. in.	9.290341 square decimeters (dm.^{2})	929.0341 cm.^{2}
1 square yard (sq. yd.)	9 sq. ft.	0.8361307 square meter (m.^{2})	83.61307 dm.^{2}
1 square rod (sq. rd.)	30.25 sq. yd.	.2529295 are	25.29295 m.^{2}
1 acre	43,560 sq. ft.	.404687 hectare (ha.)	40.4687 ares
0.15499969 sq. in.	—	1 cm.^{2}	100 mm.^{2}
.1076387 sq. ft.	15.499969 sq. in.	1 dm.^{2}	100 cm.^{2}
1.195985 sq. yd.	10.76387 sq. ft.	1 m.^{2}	100 dm.^{2}
3.95367 sq. rd.	119.5985 sq. yd.	1 are	100 m.^{2}
2.47104 acres	395.367 sq. rd.	1 ha.	100 ares

Units of Volume

United States and imperial		Metric	
1 cubic inch (cu. in.)	—	16.387162 cubic centimeters cm.^{3} or cc.)	16,387.162 cubic millimeters (mm.^{3})
1 cubic foot (cu. ft.)	1,728 cu. in.	28.317016 cubic decimeters (dm.^{3})	28,317.016 cm.^{3}
1 cubic yard (cu. yd.)	27 cu. ft.	0.7645594 cubic meter (m.^{3})	764.5594 dm.^{3}
0.06102338 cu. in.	—	1 cm.^{3}	1000 mm.^{3}
.03531445 cu. ft.	61.02338 cu. in.	1 dm.^{3}	1000 cm.^{3}
1.3079428 cu. yd.	35.31445 cu. ft.	1 m.^{3}	1000 dm.^{3}

of the earth and equals 6080.2 feet. A fathom used in nautical measurements is equal to 6 feet.

The acre, the basic unit of agricultural area measurements, contains 160 square rods or 10 square surveyor's chains. A square measuring 208.71 feet on each side is approximately 1 acre.

The relationship between the specific gravity of liquids or solids and cubic measure is of interest. Specific gravity x 1000 equals the weight in grams of 1 cubic decimeter or (very nearly) the weight in ounces of 1 cubic foot of the material. Since 1 cubic foot equals 7.4805 gallons (7.5 in round numbers), the weight-volume relationships of liquid or solid insecticidal materials can be calculated where their specific gravities are known.

Diluting Insecticidal Chemicals

EQUIVALENT QUANTITIES FOR VARIOUS QUANTITIES OF WATER

Powdered Material.—The quantity of powdered insecticidal chemical recommended for use in sprays is usually stated in pounds per 50 or 100 gallons of water. Quantities in smaller quantities of water giving the same concentration as 1 to 5 pounds in 100 gallons are shown in Table 87.

Note that the number of pounds per 100 gallons is the same as the number of ounces per 6¼ gallons. This relationship is also true for 50 and 3⅛ gallons.

Liquid Material.—Similar equivalents for use with liquid insecticidal materials, wetting agents, and the like are also shown in Table 87. The relationship of pounds and ounces noted for powdered material holds here for pints and fluid ounces.

For given x concentrations, see bottom of table.

Dilution of Liquids.—To dilute alcohol (or other liquids) using a cylinder calibrated in milliliters: Pour into the graduate as many millileters of the stronger solution as the percentage required in the weaker. Then add water until the mixture reaches the millileter mark equivalent to the percentage of the stronger solution.

Example: To make 70 per cent from 95 per cent alcohol, pour into the graduate 70 ml. of the 95 per cent solution and fill with water to the 95 ml. mark. The result is 95 ml. of a 70 per cent solution. The same procedure can be used for any other liquid.

Concentration on the Basis of Percentage of Toxicant

In the preparation of sprays, dips, or dusts with certain insecticidal chemicals, the concentration is often based on the percentage by weight of the toxicant desired in the finished insecticide. The following equations may be found useful in determining the correct quantity of insecticidal chemical to use:

Suspensions.—To determine the quantity of insecticidal chemical necessary for a given percentage of toxicant in the diluted spray,

Table 87. Quantities of insecticidal material giving the same concentration in various quantities of finished spray of 1 X concentraton[a]

Total Mixture	Insecticidal material				
			Powder		
100 gal.	1 lb.	2 lb.	3 lb.	4 lb.	5 lb.
50 gal.	½ lb.	1 lb.	1½ lb.	2 lb.	2½ lb.
25 gal.	4 oz.	8 oz.	12 oz.	1 lb.	1¼ lb.
12½ gal.	2 oz.	4 oz.	6 oz.	8 oz.	10 oz.
6¼ gal.	1 oz.	2 oz.	3 oz.	4 oz.	5 oz.
3⅛ gal.	½ oz.	1 oz.	1½ oz.	2 oz.	2½ oz.
1 gal.	4.5 g.	9.1 g.	13.6 g.	18.1 g.	22.7 g.
1 qt.	1.134 g.	2.268 g.	3.402 g.	4.536 g.	5.670 g.
1 l.	1.198 g.	2.397 g.	3.595 g.	4.793 g.	5.991 g.
			Liquid		
100 gal.	½ pt.	1 pt.	1 qt.	2 qt.	1 gal.
50 gal.	¼ pt.	½ pt.	1 pt.	1 qt.	2 qt.
25 gal.	2 fl. oz.	4 fl. oz.	8 fl. oz.	1 pt.	1 qt.
12½ gal.	1 fl. oz.	2 fl. oz.	4 fl. oz.	8 fl. oz.	1 pt.
6¼ gal.	½ fl. oz.	1 fl. oz.	2 fl. oz.	4 fl. oz.	8 fl. oz.
3⅛ gal.	¼ fl. oz.	½ fl. oz.	1 fl. oz.	2 fl. oz.	4 fl. oz.
1 gal.	2.4 ml.	4.7 ml.	9.5 ml.	18.9 ml.	37.9 ml.
1 qt.	0.591 ml.	1.183 ml.	2.366 ml.	4.732 ml.	9.463 ml.
1 l.	0.625 ml.	1.250 ml.	2.500 ml.	5.000 ml.	10.000 ml.

[a] To find the total volume (column 1) for X concentrations greater than 1 X, divide the figures in column 1 by the X concentration desired. For example, for 10 X concentration the final volume of finished spray at the top of column 1 would be $\frac{(100)}{10}$ 10 gallons instead of 100 gallons. If 100 gallons of 10 X concentration is desired, however, multiply each of the 5 corresponding dosage figures by 10. Reading across the first line at top of table the quantity of powder for 100 gals. of 10 X conc. would be 10, 20, 30, 40, and 50 pounds, respectively.

multiply the number of gallons of spray to be made by 8.345, by the per cent of toxicant desired, and divide by the per cent of toxicant in the powdered material.

Example: 100 gallons of spray containing 0.06 per cent of methoxychlor is to be prepared from a wettable powder containing 50 per cent of the toxicant. The quantity of this powder to use is—

$$\frac{100 \times 8.345 \times 0.06}{50} = 1 \text{ pound}$$

To calculate the quantity of insecticidal chemical in grams, substitute 3,785.3 for 8.345.

The percentages of toxicant in 100 gallons of spray when 1 pound of wettable powder is used, calculated for powders of eight toxicant levels, are given in Table 88. The quantities of these wettable powders necessary to give three concentration levels in 100 gallons of spray have also been calculated. These quantities may be rounded further, if necessary, in field work.

Emulsions and Solutions

Diluting by weight.—To determine the quantity in gallons of an emulsion or solution concentrate to use in making up a spray containing a given percentage of toxicant by weight, multiply the number of gallons of spray to be made by the percentage of toxicant desired, and divide by the per cent of toxicant in the concentrate times its specific gravity.

Table 88. Quantities of wettable powders of different strengths to give sprays or dips containing three concentrations of the toxicant

Percent of toxicant in wettable powder	Pounds to make 100 gallons[a]			Percent of toxicant equivalent to 1 pound per 100 gallons
	0.25 percent	0.5 percent	1 percent	
10	20.8	41.8	83.4	0.012
20	10.4	20.9	41.7	0.024
30	7.0	13.9	27.8	0.36
40	5.2	10.4	20.9	.048
50	4.2	8.3	16.7	.06
60	3.5	7.0	13.9	0.72
70	3.0	6.0	11.9	.084
80	2.6	5.2	10.4	.096
90	2.3	4.6	9.3	.108
100	2.1	4.15	8.35	.12

[a] The pounds per 100 gallons increases with increase in per cent of toxicant.

Example: 100 gallons of spray containing 2 per cent of chlordane by weight is to be prepared from a 40-per cent emulsion concentrate having a specific gravity of 1.02. The amount of the concentrate to use is—

$$\frac{100 \times 2}{40 \times 1.02} = 4.9 \text{ gallons}$$

Sufficient water is added to make 100 gallons of spray.

For field application, dosages of insecticides are often given in pounds of toxicant per acre. To determine the weight of toxicant, in pounds, in 1 gallon of emulsion concentrate, multiply 8.345 by the specific gravity of the concentrate by the per cent of toxicant in the concentrate and divide by 100.

Example: An emulsion concentrate coating 45 per cent of chlordane by weight and having a specific gravity of 1.07 is to be used. Each gallon of the concentrate contains—

$$\frac{8.345 \times 1.07 \times 45}{100} = 4 \text{ pounds of chlordane}$$

The quantity of water to be added depends on the method of application. If 1 pound of chlordane is required per acre, 1 quart of the above concentrate should be used in the quantity of spray that the apparatus at hand will deliver per acre.

Specific gravity of a product is often unknown to the average user. These formulas can be used, leaving this factor out, and the results will be close enough for rough determination.

DILUTING BY PARTS.—Emulsion and solution concentrates may be diluted by parts to obtain a desired percentage of toxicant in the finished spray or dip. It should be borne in mind, however, that 1 part of insecticidal chemical to so many parts of water is not the same as in so many parts of finished spray. The difference is of no great importance in the field use of dilute sprays, but it is of significance in the formulation of concentrated sprays and of course the distinction is desirable in the interest of precise terminology.

For diluting by parts divide the per cent of toxicant in the concentrate by the percent desired in the finished insecticide. The result is the number of parts of the finished product that must contain one part of the concentrate. The liquid-capacity measuring unit to be used will depend on the total quantity of finished insecticide needed.

Example: A dip containing 0.2 per cent of toxaphene is desired, and the concentrate contains 60 per cent of the toxicant.

$$60 \div 0.2 = 300$$

The dilution is therefore one part of the concentrate in 300 parts of finished insecticide or one part of the concentrate to 299 parts of water.

To determine the percentage of toxicant in a spray or dip made up on the basis of parts, divide the per cent of toxicant in the concentrate by the number of parts of the spray.

Example: A spray was made by diluting an extract of pyrethrum containing two per cent of total pyrethrins at the rate of one part in 100 parts of spray.

$$2 \div 400 = 0.005 \text{ per cent of pyrethrins in the spray.}$$

Weight-Volume Relationships in Dosage Estimation

Surface Application.—Dosages of residual insecticides for surface application are often given in milligrams of toxicant per square foot. If the percentage by weight of toxicant and the specific gravity of the spray are known, the approximate number of square feet that 1 gallon will cover at a stated dosage can be estimated by use of Table 89. Select the factor opposite the dosage required and under the specific gravity of the spray at hand. Multiply this factor by the percentage of toxicant in the spray. Water suspensions of wettable powder may be regarded as having a specific gravity of 1.0.

Example: We wish to estimate the approximate number of square feet that one gallon of five per cent DDT solution will cover at a dosage of 150 milligrams per square foot. The specific gravity of the oil solution is about 0.8. The factor 200 is read from Table 89 and the calculation made as follows: 200 x 5 = 1000 square feet.

Field Application.—Dosage in milligrams per square foot is approximately one-tenth the dosage in pounds per acre. The dosage figures in Table 89 can therefore be read as pounds per acre by pointing off one place. To estimate the gallonage of spray required to produce a stated dosage in pounds of toxicant per acre, divide 45,300 by the selected factor in Table 89 times the per cent of toxicant in the spray.

Example: A dosage of 2.5 pounds of DDT per acre is to be applied by airplane. The oil solution to be used contains 10 per cent of DDT and has a specific gravity of 0.9.

$$\frac{45{,}300}{1360 \times 10} = 3.33 \text{ gallons per acre}$$

Table 89. Factors for use in estimating surface coverage of residual formulations and gallonage per acre

Dosage, (mg. per sq. ft. or 144 sq. ins.)	Specific gravity and pounds per gal.				
	0.8 (6.67 lbs.)	0.9 (7.5 lbs.)	1.0 (8.34 lbs.)	1.1 (9.2 lbs.)	1.2 (10 lbs.)
10	3000	3400	3800	4200	4600
25	1200	1360	1520	1680	1820
50	600	680	760	840	930
75	400	453	506	560	614
100	300	340	380	420	460
150	200	227	253	280	307
200	150	170	190	210	230

TEMPERATURE CONVERSION. The two most commonly used thermometric systems are Centigrade (C.) and Fahrenheit (F.). Equivalents for the two scales may be calculated as follows:

$$°\text{C.} = (°\text{F.} - 32) \times 0.5556$$
$$°\text{F.} = (°\text{C.} \times 1.8) + 32$$

A number of equivalents for the two scales are presented below:

°F.	°C.	°F.	°C.	°F.	°C.
0	—17.78	80	26.67	158	70
10	—12.22	86	30	160	71.11
14	—10	90	32.22	170	76.67
20	— 6.67	100	37.78	176	80
30	— 1.11	104	40	180	82.22
32	0	110	43.33	190	87.78
40	4.44	120	48.89	194	90
50	10	122	50	200	93.33
60	15.56	130	54.44	210	98.89
68	20	140	60	212	100
70	21.11	150	65.56		

CONVERSION OF DOSAGE UNITS. To raise a dosage recommendation from a small basis to an acre basis, proceed as indicated below:

Example: The dosage recommended is 0.1 ounce per square yard. What is the dosage per acre? Multiply the dosage by 4,840, i.e. the number of square yards in an acre, and divide by 16, i.e. the number of ounces in a pound.

$$\frac{0.1 \times 4{,}840}{16} = 30.3 \text{ pounds per acre}$$

Area Covered at Specified Dosage: To determine the area which 100 pounds of a material will treat if the dosage recommended is, e.g. eight ounces per 100 square feet: Divide the 100 pounds by the rate per acre. The rate per acre is obtained by multiplying eight ounces (i.e. 0.5 pound) by 43.56, the number of 1000 square foot units in an acre.

$$\frac{100}{43.56 \times 0.5} = 4.59 \text{ acres}$$

Capacity of a Cylindrical Spray Tank. To determine the capacity of a cylindrical spray tank: Multiply the length in inches by the square of the diameter in inches, then multiply by the constant 0.0034 to obtain the answer in gallons.

Example: a tank 60 inches long, 40 inches in diameter has a capacity of:

$$60 \times 40 \times 40 \times 0.0034 = 326.4 \text{ gallons}$$

Capacity of a Rectangular Spray Tank. To determine the capacity of a rectangular spray tank: Multiply the length in inches, by the depth in inches, by the width in inches. Then multiply by the constant 0.004329 to obtain the capacity in gallons.

Example: A tank 60 inches long, 40 inches high, and 40 inches wide has a volume of:

$$60 \times 40 \times 40 \times 0.004329 = 415.8 \text{ gallons}$$

Capacity of an Elliptical Spray Tank. To determine the capacity of a spray tank with an elliptical cross section: Multiply the length in inches, by the short diameter in inches, by the long diameter in inches. Then multiply by the constant 0.0034, to obtain the capacity in gallons.

Example: A tank 60 inches long, short diameter 30 inches, long diameter 50 inches has a capacity of:

$$60 \times 30 \times 50 \times 0.0034 = 306 \text{ gallons}$$

Also,

Diameter = circumference x 0.31831
Area of circle = $(\text{diam.})^2 \times 0.7854$
Area of ellipse = product of both diameters x .7854

Table 90. Contents of Horizontal, Cylindrical Tanks

(From Bailey and Smith, 1951)

Depth	Diameter of Tank, inches											
	24	26	28	30	32	34	36	38	40	42	44	46
inches	gallons per foot of horizontal length of tank											
1	.32	.34	.36	.37	.38	.39	.40	.41	.42	.43	.44	.45
2	.93	.95	1.03	1.07	1.09	1.11	1.13	1.16	1.22	1.23	1.26	1.29
3	1.69	1.76	1.83	1.91	1.95	2.03	2.09	2.14	2.22	2.26	2.32	2.38
4	2.56	2.67	2.77	2.90	3.01	309	3.20	3.29	3.39	3.47	3.52	3.66
5	3.53	3.70	3.85	3.99	4.15	4.25	4.45	4.55	4.70	4.83	4.90	5.03
6	4.59	4.79	5.01	5.22	5.40	5.59	5.75	5.92	6.14	6.25	6.42	6.60
7	5.65	5.97	6.25	6.49	6.72	6.95	7.20	7.44	7.67	7.84	8.05	8.27
8	6.84	7.18	7.52	7.83	8.16	8.44	8.73	9.00	9.29	9.52	9.72	10.06
9	8.04	8.46	8.86	9.26	9.62	9.96	10.33	10.55	11.00	11.28	11.50	11.85
10	9.24	9.75	10.25	10.70	11.12	11.55	11.93	12.37	12.76	13.12	13.44	13.81
11	10.49	11.09	11.63	12.17	12.67	13.20	13.64	14.11	14.59	14.95	15.42	15.84
12	11.75	12.41	13.07	13.70	14.30	14.80	15.40	15.90	16.47	16.90	17.27	17.63
13	13.01	13.79	14.53	15.25	15.91	16.56	17.15	17.73	18.39	18.91	19.44	19.98
14	14.26	15.17	16.00	16.77	17.54	18.30	18.96	19.67	20.36	20.96	21.59	22.18
15	15.46	16.49	17.47	18.36	19.18	20.26	20.80	21.56	22.79	23.06	23.76	24.43
16	16.65	17.83	18.93	19.95	20.89	21.78	22.67	23.55	24.38	25.09	25.86	26.72
17	17.86	19.12	20.37	21.49	22.60	23.58	24.55	25.48	26.43	27.24	29.10	28.93
18	18.91	20.40	21.75	23.01	24.24	25.38	26.44	27.43	28.49	29.40	30.37	31.28

To find the side of a square that equals the area of any circle, multiply the circle's diameter by 0.8862.

Volume of a sphere = diam. cubed x 0.5236

Volume of a cone = area of base x ⅓ of altitude

1 cu. ft. water = 7.5 gals. = 62.5 lbs.

Pressure in p.s.i. = height (in feet) x .434

Decimal Equivalents of Fractions

1/64	.01562	33/64	.51562
1/32	.03125	17/32	.53125
3/64	.04688	35/64	.54688
1/16	.0625	9/16	.5625
5/65	.07812	37/64	.57812
3/32	.09375	19/32	.59375
7/64	.10938	39/64	.60938
1/8	.125	5/8	.625
9/64	.14062	41/64	.64062
5/32	.15625	21/32	.65625
11/64	.17188	43/64	.67188
3/16	.1875	11/16	.6875
13/64	.20312	45/64	.70312
7/32	.21875	23/32	.71875
15/64	.23438	47/64	.73438
1/4	.25	3/4	.75
17/64	.26562	49/64	.76562
9/32	.28125	25/32	.78125
19/64	.29688	51/64	.79688
5/16	.3125	13/16	.8125
21/64	.32812	53/65	.82812
11/32	.34375	27/32	.84375
23/64	.35938	55/64	.85938
3/8	.375	7/8	.875
25/64	.39062	57/64	.89062
13/32	.40625	29/32	.90625
27/64	.42188	59/64	.92188
7/16	.4375	15/16	.9375
29/64	.45312	61/64	.95312
15/32	.46875	31/32	.96875
31/64	.48438	63/64	.98438
1/2	.5		

Table 91. Contents of Rectangular Tanks
(Gallons per Foot of Depth)
(From Bailey and Smith, 1951)

Width of Tank feet	Length of Tank in feet										
	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
2	44.48	52.36	59.84	67.32	74.81	82.29	89.77	97.25	104.73	112.21	119.6
2.5	56.10	65.43	74.80	64.16	93.51	102.86	112.21	121.56	130.91	140.26	149.6
3	67.32	78.54	89.77	100.99	112.21	123.43	134.65	145.87	157.09	168.31	179.53
3.5		91.64	104.73	117.82	130.91	144.00	157.09	170.18	183.27	196.36	209.45
4			119.69	134.65	149.61	164.57	179.53	194.49	209.45	224.41	239.37
4.5				151.48	168.31	185.14	201.97	218.80	235.63	252.47	269.30
5					187.01	205.71	224.41	243.11	261.82	280.52	299.22
5.5						226.28	246.86	267.43	208.00	308.57	329.14
6							269.30	291.74	314.18	336.62	359.06

Table 92. Conversion Table for Spray Nozzle Orifices.

Number (drill size)	Size in 64ths of an inch	Size in thousandths of an inch
65	2	31
56	3	47
53	4	63
47	5	78
42	6	94
35	7	109
31	8	125
28	9	141
22	10	156

Table 93. Time Required to Empty Spray Tanks of Various Sizes. (From Bailey and Smith, 1951)

Total Delivery from all Nozzles g.p.m.	Tank Capacities (gallons)				
	100	300	400	500	600
	Time to empty in minutes				
2	51	152	200	452	300
4	25	76	100	126	150
8	13	38	50	63	75
10	10	30	40	50	60
12	8	25	33	42	50
14	7	21	29	36	43
16	6.25	19	25	31	38
18	5.55	17	22	28	33
20	5	15	20	25	30
25	4	12	16	20	24
30	3.3	10	13	17	20
35	2.9	8.6	11.4	14.3	17.1
40	2.5	7.5	10.0	12.5	15.0
45	3.3	6.7	8.9	11.1	13.3
50	2.0	6.0	8.0	10.0	12.0

Table 94. Number of Trees Per Acre in Square and Hexagonal Plantings

Distance Apart, feet	Number of Trees	
	Square Planting	Hexagonal Planting
18	134	154
20	109	125
21	99	114
22	90	103
24	75	86
25	70	80
30	48	55
35	36	41
40	27	31
45	22	25
50	17	19
60	12	14

Table 95. Required Nozzle Capacities to Apply Desired Number of Gallons of Spray per Acre.

(From Bailey and Smith, 1951)

Gallons per Acre	Nozzles 12 inches Apart on the Boom								
	Rate of Travel, miles per hour								
	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0
	Gallons per Hour per Nozzle								
5	1.88	2.25	2.63	3.00	3.38	3.75	4.13	4.50	5.25
10	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	8.4
15	4.5	5.4	6.3	7.2	8.1	9.0	9.9	10.8	12.6
20	6.0	7.2	8.4	9.6	10.8	12.0	12.2	14.4	16.8
25	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	21.0
30	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6	25.2
50	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	42.0
75	22.5	27.0	31.5	36.0	40.5	45.0	49.5	54.0	63.0
100	30.0	36.0	42.0	48.0	54.0	60.0	66.0	72.0	84.0
150	45.0	64.0	63.0	72.0	81.0	90.0	99.0	108.0	126.0
	Nozzles 15 inches Apart on the Boom								
5	1.88	2.25	2.63	3.00	3.38	3.75	4.13	4.50	5.25
10	3.75	4.50	5.25	6.00	6.75	7.50	8.25	9.00	10.50
15	5.63	6.75	7.88	9.00	10.13	11.25	12.38	13.50	15.75
20	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00	21.00

25	9.38	11.25	13.13	15.00	16.88	18.75	20.63	22.50	26.25
30	11.25	13.50	15.75	18.00	20.25	22.50	24.75	27.00	31.50
50	18.75	22.50	26.25	30.00	33.75	37.50	41.25	45.00	52.50
75	28.13	33.75	39.38	45.00	50.63	56.25	61.88	67.50	78.50
100	37.50	45.00	52.50	60.00	67.50	75.00	82.50	90.00	105.00
150	56.25	67.50	78.75	90.00	101.25	112.50	123.75	135.00	157.50

Nozzles 18 inches Apart on the Boom

5	2.20	2.70	3.15	3.60	4.05	4.50	4.95	5.40	6.30
10	4.50	5.40	6.30	7.20	8.10	9.00	9.90	10.80	12.60
15	6.75	8.10	9.45	10.80	12.15	13.50	14.85	16.20	18.90
20	9.00	10.80	12.67	14.40	16.20	18.00	19.80	21.60	25.20
25	11.25	13.50	15.75	18.00	20.25	22.50	24.75	27.00	31.50
30	13.50	16.20	18.90	21.60	24.30	27.00	29.70	32.40	37.80
50	22.50	27.00	31.50	36.00	40.50	45.00	49.50	54.00	63.00
75	33.75	40.50	47.25	54.00	60.75	67.50	74.25	81.00	94.50
100	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	126.00
150	67.50	81.00	94.50	108.00	121.50	135.00	148.50	162.00	189.00

Nozzles 20 inches Apart on the Boom

5	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	7.00
10	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	14.00
15	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00	21.00
20	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	28.00

Table 95 (Continued)

Gallons per Acre	Rate of Travel, miles per hour								
	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0
	Gallons per Hour per Nozzle								
25	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	35.00
30	15.00	18.00	21.00	24.00	27.00	30.00	33.00	36.00	42.00
50	25.00	30.00	35.00	40.00	45.00	60.00	55.00	60.00	70.00
75	37.50	45.00	52.50	60.00	67.50	75.00	82.50	90.00	105.00
100	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	140.00
150	75.00	90.00	105.00	120.00	135.00	150.00	165.00	180.00	210.00
	Nozzles 22 inches Apart on the Boom								
5	2.75	3.30	3.85	4.40	4.95	5.50	6.06	6.60	7.70
10	5.50	6.60	7.70	8.80	9.90	11.00	12.10	13.20	15.40
15	8.25	9.90	11.55	13.20	14.85	16.50	18.15	19.80	23.10
20	11.00	13.20	15.40	17.60	19.80	22.00	24.20	26.40	30.80
25	13.75	16.50	19.25	22.00	24.75	27.50	30.25	33.00	38.50
30	16.50	19.80	23.10	26.40	29.70	33.00	36.30	39.60	46.20
50	27.50	33.00	38.50	44.00	49.50	55.00	60.50	66.00	77.00
75	41.25	49.50	57.75	66.00	74.25	82.50	90.75	99.00	115.50
100	55.00	66.00	77.00	88.00	99.00	110.00	121.00	132.00	154.00
150	82.50	99.00	115.50	132.00	148.50	165.00	181.50	198.00	231.00

Air displacement in trees. For fine sprays (10 to 35 microns) and dusts delivered by mist blowers and high volume dusters the best deposit and coverage is obtained by filling the tree with dust-laden or spray-laden air. Consequently, the air which stands in the tree before treatment must be forced out by the pesticide-laden air. The machine must drive into the tree a sufficient volume of air to replace that already there. Potts' work indicated that good coverage can be obtained by replacing ¼ to ½ of the air in the tree provided the average droplet diameter is not below 35 microns. Static air was utilized to aid in covering the tree with active ingredients. The volume of air in trees of various sizes is given in Table 98.

The "distance around the tree" is the diameter times 3.1417. The "distance over the tree" represents the distance from the ground, across the highest part of the top, and down to the ground on the opposite side. This distance is roughly 2⅓ times the height of the tree. The volume of the tree can be computed by the formula:

$$\frac{C^2}{12.5664}\left(\frac{0}{2} - C\ (0.144)\right) = \text{cubic feet}$$

wherein "C" is the circumference or distance around, and "O" is the distance over the tree.

If the trees are to be sprayed from one side only by a single pass of the machine, then divide the tractor speeds in the above table by two.

When the machine is delivering from both sides and treating one side of each of two rows, divide the tractor speed by two.

Table 96. Quantities of spray material of 1x concentration required for trees of various ages in full leaf.

Age of Trees, years	Apple, gallons	Peach, gallons
1-3	¼-½	¼-1
3-5	½-2	1-2
5-6	2-3	2-3
6-8	2½-4	2½-4
8-12	3-5	3-5
12-18	5-8	4-6
18-25	8-12	4-6
25+	12-15	4-6

If the machine delivers more or less than 30,000 cubic feet of air per minute, divide the air volume of the machine by 30,000 and multiply by the tractor speed given in the above table.

To use Tables 98 and 99 Example: "A machine delivers 10,000 cubic feet of air per minute, the trees are 20 feet tall, have a leaf-area-diameter of 16 feet, and are planted 22 feet apart. The distance over a tree is then 20 x 2⅓ = 47 feet, the distance around a tree is 16 x 3.14 = 50 feet. Refer to Table 98 and the volume of air in the tree will be found to be slightly over 3,000 cubic feet. Refer to Table 99: for trees holding 3,000 cubic feet of air, and spaced at 22 feet, a tractor speed of 5 m.p.h. is indicated (for 30,000 cubic feet of air per minute delivered from one side of machine only). The speed required for a displacement of 10,000 cubic feet is calculated as follows:

$$\frac{10{,}000}{30{,}000} \times 5 = 1.7 \text{ m.p.h.}$$

"If the machine is spraying from both sides, treating two trees simultaneously, then 1.7 ÷ 2 = 0.85 m.p.h. is the desired speed of travel.

Table 97. Time Required for Machines to Cover One Acre of Orchard at Various Tractor Speeds for Various Planting Distances. (Time for Turning is Not Counted)

(From Bailey and Smith, 1951)

Planting Distance, feet	Feet of Row per Acre	Miles per Acre	Tractor Speed, miles per hour				
			0.5	1.0	2.0	4.0	6.0
			Minutes to Cover One Acre				
18	2419	0.458	55	27	14	7	4½
20	2179	0.413	50	25	13	6	4
22	1981	0.375	45	23	17	5⅔	3¾
24	1816	0.344	44	21	11	5½	3½
26	1676	0.317	38	19	10	5	3
28	1555	0.295	34	17	9	4½	3
30	1453	0.275	32	16	8	4	2¾
35	1244	0.236	28	14	7	3½	2⅓
40	1089	0.206	24	12	6	3	2
45	968	0.183	22	11	6	3	1-4/5
50	670	0.165	20	10	5	2½	1⅔
55	791	0.150	18	9	5	2½	1½
60	726	0.138	16	8	4	2	1⅓

Table 98. Volume of Air in Trees of Various Sizes.
(From Bailey and Smith, 1951)

Distance Over the Tree, feet	Distance Around the tree, feet								
	20	30	40	50	60	70	80	90	100
	Volume of Air, cubic feet								
20	227								
30	386	765	1175	1551	1822				
40		1123	1811	3546	3254	2875	4318		
50		1481	2448	3540	4686	4324	6863	7759	
60				4535	6118	5773	9409	10981	12410
70							11955	14203	16387

Table 99. Tractor Speeds to Fill a Tree with Air[a]
(From Bailey and Smith, 1951)

Spacing of Trees, feet	Volume of Air in Tree, cubic feet							
	2000	3000	5000	7000	9000	12000	14000	16000
	Tractor Speed, miles per hour							
18	6.13	4.09						
20	6.82	4.55	2.73					
22	750	5.00	3.00	2.14				
24	8.18	5.45	3.27	2.34	1.84	1.36		
30	10.23	6.82	4.09	2.92	2.24	1.70	1.46	1.29
40		9.09	5.45	3.90	3.03	2.27	1.95	1.70
50		11.36	6.82	4.87	3.79	2.84	2.43	2.13
60			8.18	5.84	4.55	3.41	2.92	2.58

[a] Above taple is based on the assumption that the machine produces 30,000 cubic feet of air per minute, and the machine travels each row, thereby spraying each tree from two sides.

"To find the time required to cover one acre at 0.85 m.p.h. in a 22 foot planting, turn to Table 97 and the time is found to be 26½ minutes."

Courses of Instruction

THE concentrated spray method and the information relating to it and to its use have been developed for the most part outside the teaching profession. Furthermore, many research and extension workers in the U. S. Dept. of Agriculture and in the state experiment stations have only recently begun to learn the rudiments of concentrated spray application. Because they are unfamiliar with

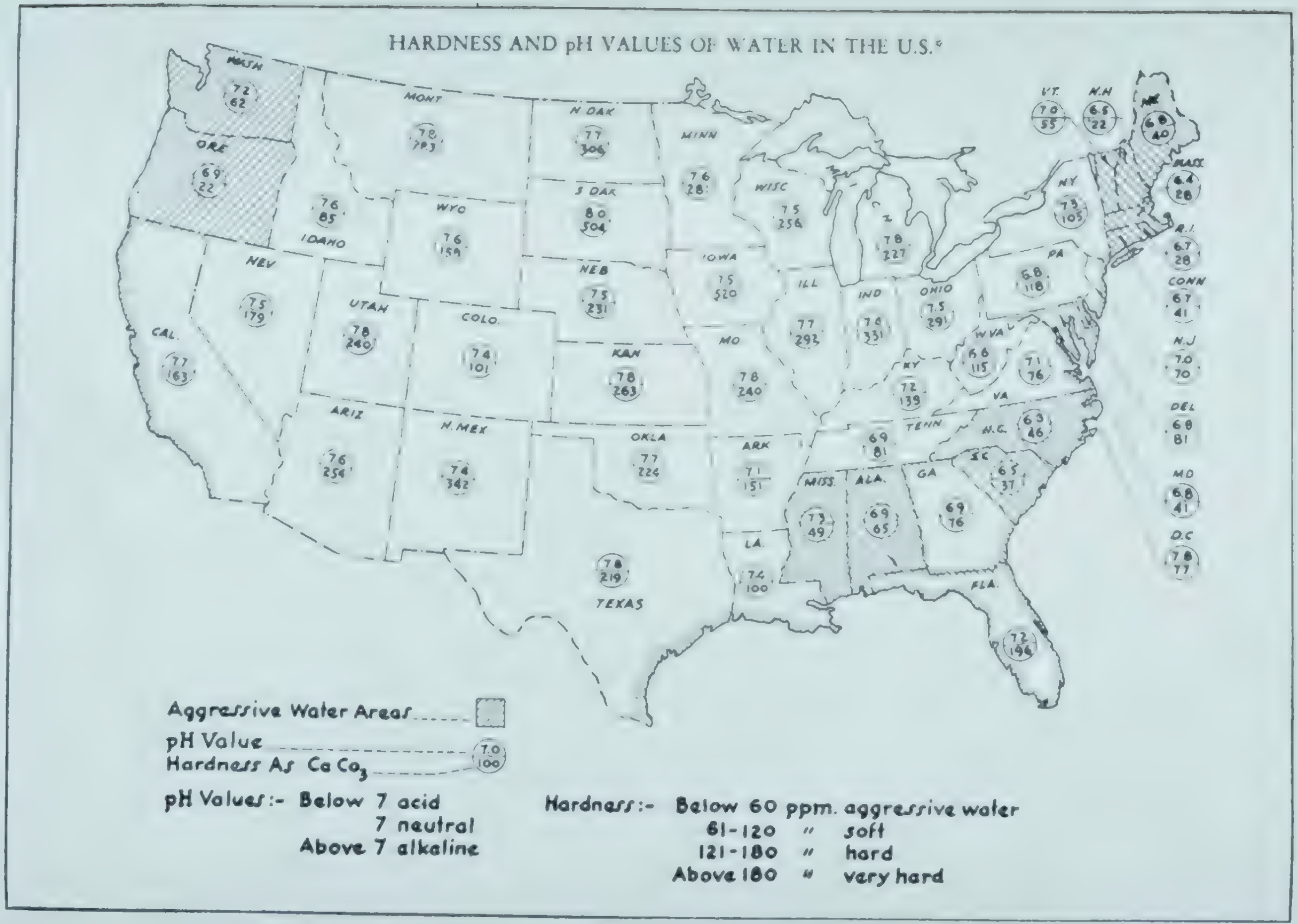

HARDNESS AND pH VALUES OF WATER IN THE U.S.[6]
WASH 7.2 62
ORE 6.9 22
CAL. 7.7 163
NEV 7.5 179
IDAHO 7.6 85
MONT 7.8 283
WYO 7.6 159
UTAH 7.8 240
COLO. 7.4 101
ARIZ 7.6 254
N. MEX 7.4 342
N. DAK 7.7 306
S. DAK 8.0 504
NEB 7.5 231
KAN 7.8 263
OKLA 7.7 224
TEXAS 7.8 219
MINN 7.6 281
IOWA 7.5 520
MO 7.8 240
ARK 7.1 151
LA. 7.4 100
WISC 7.5 256
ILL 7.7 293
MISS. 7.3 49
MICH 7.8 227
IND 7.4 331
KY 7.2 139
TENN 6.9 81
ALA. 6.9 65
OHIO 7.5 291
W. VA 6.6 115
VA 7.1 76
N.C. 6.3 46
S.C. 6.5 37
GA 6.9 76
FLA. 7.2 196
PA 6.8 118
NY 7.3 105
VT. 7.0 55
N.H 6.5 22
ME 6.8 40
MASS 6.4 28
R.I. 6.7 28
CONN 6.7 41
N.J 7.0 70
DEL 6.8 81
MD 6.8 41
D.C 7.8 77
Aggressive Water Areas ▨
pH Value 7.0
Hardness As CaCO3 100
pH Values:- Below 7 acid
7 neutral
Above 7 alkaline
Hardness:- Below 60 ppm. aggressive water
61-120 " soft
121-180 " hard
Above 180 " very hard

Figure 154. Hardness and pH values of water in the United States.

Reprinted by special permission of the American Iron and Steel Institute.

this method they continue to recommend the old methods with which they are familiar to the exclusion of concentrated sprays. Many would-be users of concentrates shy away from using them because the failure of official agencies and colleges to mention concentrated sprays has led them to conclude that the method is not satisfactory.

With the exception of a few students from one institution, I have yet to see a graduate who came out of college well versed in the use of new control methods, including concentrated spray application. Usually when the students were asked why they didn't come prepared to do the work they were hired to do, they merely explained it away by saying that their schools had no such courses to offer, and that it was the fault of the teachers. Some had gotten course information on insecticide and fungicide concentrates from the pomology and arboriculture departments. Others had obtained a little information on herbicide concentrates from agronomy departments. But most college departments of entomology, plant pathology, plant physiology, and agricultural engineering have been backward in this field. The loss in values is enormous for time, service and research lost while trying to train students for the work after they leave college.

Analysis of the Problem

IN discussing this matter with instructors and professors I find they give several legitimate excuses about as follows:

1. We never received instruction and training in the various phases of concentrate application.
2. There was little or no data available, covering dosage, gallonage, formulations and methods for all pesticides and all pests.
3. We have no aerial equipment, and in fact little or no ground concentrate spray equipment to use in testing, or for use in class work, instruction and demonstration.
4. Lack of funds and teachers.

Actually no institution today has the instruction facilities to adequately serve this new concept of chemicals application. Some feel that it might be advantageous to combine the facilities of several schools within a region to provide a few well-qualified teaching establishments. This does not in any way lessen the need for basic college training in such subjects as taxonomy, morphology, micology, histology, physiology, toxicology, ecology, biochemistry and statistical analysis.

Table 100. Calibration for broadcast spraying of herbicides in gallons per acre with Spraying Systems Company[b] nozzles spaced 20 inches apart.

(From Miss. Agr. Exp. Sta. Cir. 195, 1955)

Nozzle size	Pressure	Speed in miles per hour															
		2.6	2.8	3.0	3.2	3.4	3 6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	6.0	7.0	8.0
	20	8.0	7.6	7.1	6.6	6.2	5.9	5.5	5.2	5.0	4.8						
	30	10.4	9.7	8.6	8.5	7.9	7.6	7.1	6.8	6.4	6.1	5.8	5.7	5.1			
8001	40	11.5	10.8	10.0	9.4	8.8	8.4	7.9	7.5	7.1	6.8	6.5	6.3	6.0	5.0		
	20	12.6	11.9	10.5	10.3	9.7	9.2	8.7	8.2	7.8	7.5	7.2	6.9	6.3	5.5		
	30	15.0	14.0	12.9	12.2	11.4	10.9	10.3	9.8	9.2	8.8	8.4	8.2	7.7	6.5	5.6	
80015	40	17.2	16.2	14.9	14.1	13.2	12.6	11.8	11.2	10.6	10.2	9.8	9.4	8.9	7.5	6.4	
	20	16.1	15.1	14.0	13.2	12.3	11.8	11.1	10.5	9.9	9.5	9.1	8.8	8.4	7.0	6.0	5.2
	30	19.6	18.4	17.2	16.0	15.0	14.3	13.4	12.8	12.1	11.6	11.0	10.7	10.3	8.5	7.3	6.3
8002	40	23.0	21.6	19.8	18.8	17.6	16.8	15.8	15.0	14.2	13.6	13.0	12.6	11.8	10.0	8.6	7.4
	20	24.2	22.7	20.9	19.7	18.5	17.6	16.6	15.8	14.9	14.3	13.6	13.2	12.6	10.5	9.0	7.8
	30	29.9	28.1	25.8	24.4	22.9	21.8	20.5	19.5	18.5	17.7	16.9	16.4	15.4	13.0	11.2	9.6
8003	40	34.5	32.4	29.6	28.2	26.4	25.2	23.7	22.5	21.3	20.4	19.5	18.9	17.8	15.0	12.9	11.1
	20			28.0	26.3	24.6	23.5	22.1	21.0	19.9	19.0	18.2	17.6	16.8	14.0	12.0	10.4
	30			34.3	32.9	30.8	29.4	27.6	26.2	24.8	23.8	22.8	22.0	18.7	17.5	15.0	13.0
8004	40			39.6	37.6	35.2	33.6	31.6	30.0	28.4	27.2	26.0	25.2	20.6	20.0	17.2	14.8

---

[a] **Speed of tractor should be determined under operating conditions**

Example: It has been determined that the speed of the tractor is 3.4 miles per hour and a total volume rate of 15 gallons per acre is to be used. Read down under 3.4 in the "speed" column to 15.0; this shows that an 8002 nozzle should be employed at 30 p.s.i. If 2,4-D is to be applied at a rate of $^3/_4$-pound per acre, three pints of the 2,4-D concentrate (containing 4 pounds of acid equivalent per gallon) is added to 13-$^3/_4$ gallons of water. **This amount should be applied to one acre.**

[b] Other suitable types of nozzles with correct spraying angle and orifice size can be substituted for the above nozzles.

Table 101. Calibration data for pre-and post-emergence herbicidal spraying with Spraying Systems nozzles.
(From Miss. Agr. Expt. Sta., Cir. 195, 1955)

M.P.H.	Seconds to travel 300 ft.	Nozzle [a] sizes	Approx. gauge pressure (p.s.i.)	Seconds to fill 1 qt. from 1 nozzle	Nozzle sizes [a]	Approx. gauge pressure (p.s.i.)	Seconds to fill 1 qt. from 1 nozzle
PRE-EMERGENCE APPLICATIONS							
	12 gals./acre [b] water solution				6 gals./acre [b] water solution		
2.2	93	8002	32	84	8001	32	168
2.4	85	8002	38	77	8001	37	154
2.6	79	8003	20	71	8001	45	142
2.8	73	8003	23	66	80015	22	132
3.0	68	8003	26	62	80015	26	124
3.2	64	8003	30	58	80015	29	116
3.4	60	8003	34	55	80015	33	110
3.6	57	8003	38	52	8002	21	104
3.8	54	8004	24	49	8002	23	98
4.0	51	8004	26	46	8002	26	92
4.2	49	8004	29	44	8002	30	88
4.4	46	8004	32	42	8002	33	84
4.6	44	8004	35	40	8002	36	80
4.8	43	8004	38	39	8002	38	77
5.0	41	8004	41	37	8002	40	74

Table 101 (Continued)

M.P.H.	Second to travel 300 ft.	Nozzle[a] sizes	Approx. gauge pressure (p.s.i.)	Seconds to fill 1 qt: from 1 nozzle	Nozzle sizes[a]	Approx. gauge pressure (p.s.i.)	Seconds to fill 1 qt: from 1 nozzle
POST-EMERGENCE OILS							
		5 gal./acre [c]			7 gal./acre [c]		
2.2	93	800050[d]	17	404	650067[d]	18	289
2.4	85	800050	20	370	650067	22	266
2.6	79	800050	24	342	650067	26	245
2.8	73	800050	27	318	650067	30	227
3.0	68	800050	32	297	650067	34	212
3.2	64	650067	20	278	8001	18	199
3.4	60	650067	23	262	8001	20	188
3.6	57	650067	25	247	8001	22	177
3.8	54	650067	28	234	8001	25	168
4.0	51	650067	31	222	8001	27	159
4.2	49	650067	34	212	8001	30	152
4.4	46	8001	15	202	8001	33	144
4.6	44	8001	19	193	80015	16	139
4.8	43	8001	20	185	80015	18	133
5.0	41	8001	22	178	80015	19	127

[a] Other type nozzles with correct degree of angle and orifice size may be substituted for nozzles listed.
[b] Total gallons solution per acre on 12-inch band with rows spaced 40 inches apart, 1 nozzle per row.
[c] Total oil per acres with rows spaced 40 inches apart.
[d] Two nozzles required per row for herbicidal oils.

Other Groups

OTHER groups clearly in need of instruction and training include research and extension workers, foresters, agronomists (with special reference to grass and weed control), pest control operators; shade tree experts and arborists; mosquito and fly control operators; crop, pasture, grain pest control workers; forest spray operators; airplane operators and pilot trainees for agricultural aerial work; spray chemical (pesticides, nutrient and fertilizer) manufacturers and processors; and manufacturers of pesticide application equipment. The ordinary 2 to 5 day college short courses are not sufficient for most of these groups.

Possible Agencies and Instruction

TO instruct and accommodate these large groups properly would require a substantial staff of trained instructors, a complete line of hand and power equipment and sufficient airplanes, helicopters, mechanics, pilots and fields. It seems likely that most of the training work could be limited to the fall and spring months. It is open to question as to whether such a set-up should be operated as a state college sponsored unit, a private institution, or a federal establishment. It could supplement and not conflict with established colleges. Apparently one such outfit should exist in each of several regions. Whether the proposed establishment should also conduct fundamental and applied research and developmental work on a year-around schedule is also open for consideration.

The staff for conducting the training program must consist of entomologists, engineers, chemists, agronomists, herbicide specialists, plant nutrition experts, pilots, and field operators with experience and know-how covering every phase of concentrate application. No one individual knows all phases thoroughly, but the whole field and the interest of each group can be covered by selecting for each phase of study, one or more instructors who are familiar with it. Some of them must know thoroughly the state applicator laws, labor laws, and safety measures required of pest control operators. The selection of this staff must be guided by the fact that we are fast out-living the day when insecticides and other pesticides and nutrients each require a separate branch specialist and a separate application. Pesticide and nutrient application of the future will be a "package deal" operation by pesticide experts who are familiar with all phases of operation including how to safely mix and apply several insecticides, fungicides, herbicides and fertilizers in the same application.

MIST BLOWER DATA SHEET

Plot No. ________

Species of pest ....Place ________ Time ________

Stage of instar ....Date ....

Machine: Mixture:

Kind ________

Rate of travel (m.p.h.) ....

Output (gals./hr.) ....

Kind of nozzle .... Quantity applied ....

No. of nozzles ________

Nozzle position .... particle size ________

Meteorological factors:

Wind:

Direction in relation to plot ....

Velocity (m.p.h.) ....

Temp. °F ________

Relative humidity % ________

Sky condition ________

Degree of coverage (excellent, good, fair, poor) ________

Infestation:

Before treatment ________

After treatment ________

Defoliation or damage ________

Area and shape of plot ....

Topography ________

Growth: Height, d.b.h., species, density ....

Area of foliage per acre .... Foliage injury ....

Notes at time of treatment and subsequent visits:

Acreage ________

Time required ________

No. of trees ________

Please make a rough sketch of the plot on the reverse side of this sheet.

Material for Instruction

ONE of the many, much needed tools for instruction that some unit such as the above could provide is illustrative material in the form of exhibits, films, kodachrome slides, photographs, drawings, and charts. Sufficient duplicates of this material should be available to supply colleges, experiment stations, extension services and various other agencies. In movies and photographs alone it is estimated that a minimum of thirty, 15 to 30 minute films and 500 assorted pictures would be required to adequately cover the whole field. All colleges, scientific agencies, and commercial concerns that were contacted, reported a big lack of, and need for, this illustrative information.

The bulk of course material and exercises must, of course, consist of other things than the illustrative items mentioned above. That is one reason for this book. It was originally planned to have one chapter deal exclusively with course outlines and course material. That chapter was abandoned after it became apparent that the book would be much longer than had been planned for. However, the essential course material, information and methods are contained throughout the book.

In the training process, nothing can compensate for: guided actual experience in using, repairing, and maintaining all kinds and sizes of equipment on all kinds of plants and trees; preparation of spray mixtures; operations methods; sampling for deposit, distribution, and coverage measurements; particle size measurement; foliage injury studies; testing techniques and methods; screening tests; and dozens of other phases of concentrated spray and aerosol application.

With a large array of equipment and numerous available pesticides, nutrients and combinations having specific and unique characteristics, and with highly variable field conditions to be met, we are rapidly approaching what might be termed the day of prescription pesticide science. Many agricultural pest control operators and consultants of the future may carry an operator's license and examination certificate regardless of whether they have a college degree or not. The pest control job is becoming too complicated for the average grower. More and more they are hiring experts and equipment owners to perform these services. Large cotton plantations, canning companies, citrus growers, orchardists and land managing agencies, in recognition of this trend, now employ trained entomologists and

AIRPLANE AND HELICOPTER SPRAY TEST

Data by .... Date ....

Insect .... Stage .... Host Plant ....

PLOT: Location ....

Size .... Topography .... Elevation ....

Exposure .... Slope ....

Type of Cover .... Density of cover ....

AEROLOGY: Wind (a) direction ...... (b) velocity ...... Temperature .

Humidity .... Lapse rate .... Weather ....

INSECTICIDE: Composition ....Application rate ....

APPARATUS: Type ....Pressure ....

Nozzle type and size ....

Discharge rate .... Other ....

FLIGHT DATA: Direction .... Height ....

Speed .... Swath Pattern ....

Ferry base to service point (a) distance..........(b) Time......

Ferry service point to plot (a) distance..........(b) Time......

Service time .... Breakdown time ....

Time over plot (a) spraying .... (b) turning ....

Particle size ....

TIMELOG:

Map and other notes

SAMPLING METHOD ....

Deposit .... % Recovered ....

% Deposited : upper leaf surface....................Drift..........

: lower leaf surface....................

: ground ....

RESULTS: Coverage ....

Mortality ....

Foliage injury observation ....

other scientists to check crops and either supervise, conduct, or recommend appropriate specific control measures. Still others with training may establish agricultural chemicals stores and garden centers and accomplish much the same objective by providing sound technical advice with each sale, thus rendering a service comparable to that provided by a reputable pharmacist. We should not further delay the development of curricula and facilities to adequately prepare students, teachers, researchers, pest control experts and others for entry into these fields.

Any course of instruction should include numerous note forms and data sheets. Examples of two of these are shown (pages 572-574). One is for mist blower application and the other one is for aerial application. Also, many types of testing schemes are required such as the slide-pulling-rope device for tall trees; the slide and ball placement system for fruit trees; the leaf, slide and stake method for crops; and the ground and canopy sampling schemes for aircraft testing, etc.

Pest Control Applicator Examinations

MANY states are now requiring pest control operators to take examinations on various kinds of pest control work. The nature of the work, the qualifications and the kinds of questions vary with the kind of control work, the chemicals to be used, the kind of application equipment involved and other factors. The applicator's examination for cotton treatment will be different from that for fruit, or for forest spraying, or for nutrient and fertilizer application, or for herbicide and silvicide dispersal. These several types of examinations have been deleted from the present manuscript because of the large number of pages required.

An example of one type of examination is given on the following pages, not as an ideal set of questions, but merely as an illustration of one type.

Face of Applicator Examination Form

STATE OF ARIZONA
BOARD OF PEST CONTROL APPLICATORS
Sky Harbor Airport

PEST CONTROL APPLICATOR EXAMINATION

PLEASE READ

If you fail this examination you must wait 14 days before you can retake the examination.
You will be allowed one hour to complete this examination.
Try to answer every question.
Each question is worth three points.
A grade of 75% is required to pass the examination.

……………………………………………

……………………………………………

Questions

1. When applying pesticides to control insects, the pesticide can act as a stomach poison, by contact, by fumigation, or by all three modes of action.
   TRUE ☐ FALSE ☐
2. Sprays are equivalent to dusts for the control of many insects.
   TRUE ☐ FALSE ☐
3. Usually the same amount of toxic ingredient is required per acre for both dusts and sprays for effective insect control.
   TRUE ☐ FALSE ☐
4. Systox (demeton) at the rate of 4-6 oz. per acre will give over 90% control of spider mites, the cotton aphid, bollworms, the yellow clover aphid, and beet army worms.
   TRUE ☐ FALSE ☐
5. Applicators applying organic phosphates should have on hand one of the following antidotes for phosphate poisoning.
   Benzedrine ☐ Atropine ☐
   Anti-Histamine ☐ Cortisone ☐
6. Select five of the eight insects listed below which are commonly found on cotton in Arizona.

Boll weevils ………………… ☐
Khapra beetles ………………… ☐
Bollworms ………………… ☐
Stink bugs ………………… ☐
Lygus bugs ………………… ☐
Thrips ………………… ☐
Saltmarsh caterpillars ……… ☐
Aphids ………………… ☐

7. If an insecticide label reads 2-10-40, what are the percentages of active ingredients within the bag?

2% BHC, 10% DDT, 40% Sulphur .... ☐
2% Sulphur, 10% DDT, 40% BHC .... ☐
2% DDT, 10% Sulphur, 40% BHC .... ☐
2% BHC, 10% Sulphur, 40% BHC .... ☐

8. If you are instructed to apply a combination of Toxaphene, DDT and Sulphur (15-5-40) at 20 pounds per acre on a field of melons for the control of aphids, you should:

a. Apply the material in the morning. ☐

b. Contact the grower or insecticide firm and question the selection of materials. ☐

c. Survey the adjoining area to make sure there are not cotton fields adjoining the field. ☐

9. Select two of the following materials which are used to control the bollworm.

TOXAPHENE ☐ ENDRIN ☐ DDT ☐ SULPHUR ☐

10. Aircraft cannot be legally used to apply sulphur unless the exhaust outlet is:

(a) Above the center line of the fuselage ☐
(b) more than three feet from the spreader ☐
(c) More than three inches in diameter ☐

11. The timing of insect control treatment has no bearing on the effectiveness of the control.

TRUE ☐ FALSE ☐

12. Applying 12 gallons per acre using a 33′ swath would require how many gallons for a ¾ mile run?

(a) 54 gal. ☐ (b) 36 gal. ☐ (c) 29 gal. ☐ (d) 44.4 gal. ☐

13. Custom applications made by me as an applicator must be reported to the Board of Pest Control Applicators in the following period after completion:

(a) 90 days ☐ (b) 30 days ☐ (c) 15 days ☐ (d) 60 days ☐

14. Any employee you suspect of being sick from an organic phosphate material should be:

(a) Discharged ☐ (b) Taken to a doctor ☐ (c) Sent home ☐

15. Dusting alfalfa at the rate of 20 pounds per acre you have put on 600 pounds in 10 passes. The field is ½ mile long. Your application is correct if you are moving:

(a) 33′ ☐ (b) 50′ ☐ (c) 42′ ☐ (d) 60′ ☐

16. Using a 50′ swath, how many swaths are required to do an 80 acre field which is being treated the long way?
The field is considered to be a standard ½ mile by ¼ mile.

(a) 16 passes ☐ (b) 26 passes ☐ (c) 44 passes ☐ (d) 18 passes ☐

17. You are spraying a material containing 6 pounds of active ingredient per gallon, and are applying ¾ pound of material per acre in a 5 gallon application per acre. To make a 140 gallon load for your tank, how many gallons of material are required?

(a) 5 gal. ☐ (b) 3 gal. ☐ (c) 4 gal. ☐ (d) 3.5 gal. ☐

18. You are using a 42′ swath. On a ½ mile run you are covering how many acres per pass?

(a) 3 acres ☐ (b) 5 acres ☐ (c) 2½ acres ☐ (d) 4 acres ☐

19. If, on opening a container of spray which is not being used as a herbicide, you detect one of the following odors you would not use it.

(a) Toxaphene ☐ (b) 2,4-D ☐ (c) Rotenone ☐ (d) BHC ☐

20. In instructing a flagman to move over 42′ per pass, you would have him move how many strides for the average man?

(a) 14 ☐ (b) 17 ☐ (c) 19 ☐ (d) 21 ☐

21. Which is the most dangerous to have on your person while working with sulphur?

(a) Safety matches ☐ (b) Wooden matches ☐ (c) Cigarette lighter ☐

22. It is unlawful to engage in the business of the custom application of pesticides in the State of Arizona without carrying Workmen's Compensation Insurance if you have the following number of employees:

One ☐ Two ☐ Three or more ☐

23. It is illegal to land an aircraft on a public right of way in the State of Arizona.

TRUE ☐ FALSE ☐

24. Cotton plants are sufficiently mature for defoliation when the bolls can be sliced easily ☐, cannot be sliced easily ☐.

25. Good defoliation will result when, the top leaves ☐, upper half of the plant ☐, all leaves ☐, are covered by the defoliant.

26. Thorough cleaning of equipment, is ☐, is not ☐, as important after applying defoliants as after the application of insecticides.

27. Around which area in the state have certain boundaries been drawn and the enclosed area been declared a hazardous zone for aerial application of Pesticides:

Tucson ☐ Phoenix ☐ Yuma ☐ All three areas ☐

28. All aircraft must have one of the following before they can be licensed to apply pesticides in the State of Arizona: Workable navigation lights ☐, a standard dust spreader ☐, shoulder harness and crash helmet for all pilots ☐.

29. Any violation of the terms of House Bill No. 175 shall be deemed a misdemeanor and punishable by:

(a) A fine of $100.00 or 10 days in the county jail or both. (b) A fine of $1000.00 (c) A fine of not more than $300.00 for each violation, or by a term in the county jail not to exceed 60 days or by both fine and imprisonment.

30. After a hearing as duly provided, the Board may refuse to grant a license or renewal of a license and may revoke or suspend any license for at least two of the following:

(a) Starting application work before sunrise ☐ (b) Failure to obtain an applicator's license ☐ (c) Failure to report applications of pesticides within the required time ☐ (d) Failure to notify the grower that the application job has been completed ☐ (e) Failure to carry the proper amount of insurance ☐.

31. Best results are obtained from a dusting application when the wind is blowing 3 to 6 miles per hour ☐, 10 to 15 miles per hour ☐, 15 to 17 miles per hour ☐.

32. You are given 100 gallons of a certain pesticide. There are 7 pounds of actual toxicant in every gallon of the pesticide. A grower asks you to spray 145 acres of his field in the morning using 2½ pounds of actual toxicant per acre. How much of the 100 gallons would you use?

20.6 gallons ☐ 51.8 gallons ☐ 25.9 gallons ☐ 58.1 gallons ☐

33. All applicators and equipment licenses expire on what date .... of the calendar year for which they are issued.

....

Number of Correct Answers

____

Examination O. K.

Respiratory Devices for Protection Against Inhalation Hazards of Dusts, Mists, and Low Vapor Concentrations of Certain Insecticides.

(From Release of June 27, 1955, supplied by H. L. Haller, Asst. Director, Crops Research, A.R.S., U.S.D.A., Washington, D. C.)

The following commercially available respirators have been tested and found to give adequte protection against dusts, mists, and low vapor concentrations of aldrin, dieldrin, endrin, chlordane. EPN, parathion, and nicotine, but not against TEPP and demeton vapors.

Respirator No. 5055 equipped with R-55 filter and cartridge unit. Two units attached to facepiece. (American Optical Co., Southbridge, Mass.)

Healthguard Respirator style 95 equipped with Code B cartridge and filter 1000 or 1001. One unit attached to facepiece. (Chicago Eye Shield Co., 2300 Warren Boulevard, Chicago, Ill.).

Farm Spray Respirator equipped with cartridge No. CR-49293 and filter No. 49294. Two units attached to facepiece. (Mine Safety Appliances Co., Braddock, Thomas and Meade Streets, Pittsburgh, Pa.).

DC 5100 Aluminum Body Respirator equipped with DMA cartridge and P-7 filter. Two units attached to facepiece. (Pulmosan Supply Equipment Corp., 644 Pacific St., Brooklyn 17, N. Y.).

Agrisol Dust and Vapor Respirator equipped with R-414 filter and 11-A Agrisol cartridge. Two units attached to facepiece. (Willson Products, Inc., Reading, Pa.).

The respirators listed below will give adequate protection against TEPP and demeton vapors as well as parathion, aldrin, dieldrin, endrin, chlordane, EPN, and nicotine. All of the respirators have two cartridge units attached to the facepiece.

Respirator No. 5561 equipped with filter cartridge combination R-561. (American Optical Co., Southbridge, Mass.).

Farm Spray Respirator No. CR-72183 equipped with cartridge No. CR-49293 and filter No. 73488. (Mine Safety Appliances Co., Pittsburgh, Pa.).

All Vision Chemical Cartridge Respirator No. CR-74910 equipped with inner cartridge No. CR-73841 and outer cartridge No. 73927. (Mine Safety Appliances Co., Pittsburgh, Pa.).

Agritox Respirator equipped with cartridge No. 11A and filter No. R490. (Willson Products, Inc., Reading, Pa.).

Field Use and Care of Respirators

The use of respirators is advised for protection from dusts or mists during field handling of and open field exposure to the insecticides mentioned. *Their use is not a substitute for essential precautions.*

It is especially important that respirators be used in handling the insecticides during the loading of distribution equipment, when disposing of empty containers, and whenever operators are exposed to obvious amounts of dusts or mists. Field operators who may be exposed to small amounts of insecticide—even those not obviously detectable—continuously during the day or for succeeding days should faithfully use respirators as a precaution.

Respirators will give adequate protection to airplane pilots during normal dusting or spraying operations, but gas masks should be worn when exposed to high concentrations. Pilots should take care to select and wear goggles that give a tight seal with the respirator around the nose piece. In the use of respirators the following practices are highly important:

(1) Change filters twice a day, or oftener, should breathing become difficult.

(2) Change cartridges after 8 hours of actual use, or oftener, if any odor of the insecticide is detected.

(3) Remove filters and cartridges and wash facepiece with soap and warm water after use. After washing, rinse thoroughly to remove all traces of soap. Dry facepiece with clean cloth, uncontaminated with insecticide. Place facepiece in a well ventilated area to dry.

(4) Store respirator, filters, and cartridges in a clean dry place—preferably in a tightly closed paper or plastic bag.

The respirator should be fitted properly on the face, not too high on the nose, with narrow portion over the bridge of the nose, and chin cup contacting under side of the chin. Headbands should be adjusted just tightly enough to insure a good seal. Manufacturers can supply special facepieces, if the standard one does not fit.

Respirators Not Advised for Certain Uses

RESPIRATORS do *not* provide needed protection from inhalation of insecticide dust, mist, and vapors for use by:

(1) Those formulating or mixing insecticides in closed or inadequately ventilated spaces.

(2) Those applying insecticides, including aerosols, in greenhouses.

Full-face gas masks equipped with tested canisters should be worn under these conditions. The following gas-mask canisters have been found to give adequate protection against all the insecticides mentioned above:

Canister Type 2-OVAG or No. 15-OVAG-F Insecticide Canister. (Acme Protection Equipment Co., 3037 W. Lake St., Chicago, Ill.).

Canister GMC-1. (Mine Safety Appliances Co., Pittsburgh, Pa.).

Canister G3FD. (Willson Products, Inc., Reading, Pa.).

Universal type canister of any manufacturer. Type N, bearing Bureau of Mines approval.

The gas mask is worn with proper protective clothing when applying insecticides in greenhouses or other enclosed spaces. When applying grain fumigants, recommendations of the fumigant manufacturer should be followed closely.

This release supersedes previous ones and brings the information up-to-date.

Formulation Specifications

Federal and military specifications for spray mixtures and aerosols can be obtained from the following sources:

ARMY: Chief, Research and Development Laboratories
Philadelphia Quartermaster Depot
Attention: Specification Branch
2800 South 20th Street
Philadelphia 45, Pa.

NAVY: Bureau of Supplies and Accounts
Navy Department
Washington 25, D. C.

Federal specifications may be obtained from the nearest regional office of the General Services Administration as listed below:

Region	*Address*
1	Room 620, Post Office and Court House, Boston 9, Mass.
2	250 Hudson Street, New York 13, N. Y.

3 General Services Adm., Regional Office Bldg., 7th and D Streets, S. W., Washington 25, D. C.
4 50 Whitehall Street, S. W., Atlanta, Ga.
5 Courthouse, 219 South Clark Street, Chicago, Ill.
6 Federal Office Building, Kansas City, Mo.
7 1114 Commerce Street, Dallas, Texas.
8 Bldg. 41, Denver Federal Center, Denver, Colo.
9 630 Sansome Street, San Francisco 11, Calif.
10 U. S. Courthouse, Seattle, Washington.

The U. S. Department of Agriculture has not ordinarily issued specifications but uses the Federal specifications when applicable. Each year some old specifications are revised and new ones drawn up.

Manufacturers of Emulsifiers, Wetting Agents, and Spreaders

Advance Solvents & Chemical Corp.
254 Fifth Avenue
New York, N. Y.

Alox Corp.
3943 Buffalo Avenue
Niagara Falls, N. Y.

Alrose Chemical Co.
180 Mill Street
Cranston, R. I.

American Cyanamid Co.
30 Rockfeller Plaza
New York, N. Y.

Antara Chemicals
435 Hudson St.
New York 14, N. Y.

Armour & Co.
1355 West 31st Street
Chicago, Ill.

Arnold, Hoffman & Co.
55 Canal Street
Providence, R. I.

Atlantic Refining Co.
260 South Broad Street
Philadelphia, Pa.

Atlas Powder Co.
Delaware Trust Bldg.
Wilmington, Del.

Carbide & Carbon Chemicals Corp.
30 East 42nd Street
New York, N. Y.

Ciba Co.
627 Greenwich Street
New York, N. Y.

W. A. Cleary Corp.
New Brunswick, N. J.

Commercial Solvents Corp.
Terre Haute, Ind.

Dewey & Almy Chemical Co.
62 Whittemore Avenue
Cambridge, Mass.

E. F. Drew & Co.
Boonton, N. J.

Durham Chemical Co.
4124 E. Pacific Way
Los Angeles, Calif.

Emery Industries Inc.
Box 1805
Cincinnati, Ohio

Emulsol Corp.
75 East Wacker Drive
Chicago 3, Ill.

Esso Standard Oil Co.
26 Broadway
New York, N. Y.

General Aniline Division
Allied Chemical & Dye Corp.
435 Hudson Street
New York, N. Y.

General Dyestuff Corp.
731 South Plymouth Court
Chicago, Ill.

Glyco Products Co., Inc.
230 King Street
Brooklyn, N. Y.

Griffin Chemical Co.
San Francisco, Cal.

Hercules Powder Co.
900 Market Street
Wilmington, Del.

Heyden Chemical Corp.
50 Union Square
New York, N. Y.

E. F. Houghton & Co.
West Somerset Street
Philadelphia, Pa.

Kern Products Co.
227 High Street
Newark, N. J.

Kessler Chemical Co.
7286 State Road
Philadelphia, Pa.

Monsanto Chemical Co.
1700 South Second Street
St. Louis, Mo.

National Aniline & Film Corp.
40 Rector Street
New York, N. Y.

Nopco Chemical Co.
Harrison, N. J.

Onyx Oil & Chemical Co.
Jersey City, N. J.

Oronite Chemical Co.
Russ Bldg.
San Francisco 4, Cal.

Quaker Chemicals Products Corp.
Lime, Elm & Sandy Streets
Conshohocken, Pa.

Rohm & Haas Co.
222 West Washington Square
Philadelphia, Pa.

Sharples Chemicals, Inc.
23rd & Westmoreland Streets
Philadelphia, Pa.

Sole Chemical Co.
Chicago, Ill.

Stepan Chemical Co.
427 W. Randolph St.
Chicago 6, Ill.

Theodore Riedeburg Associates
415 Lexington Avenue
New York 17, N. Y.

Titan Chemical Products, Inc.
60 Mill Road
Jersey City, N. J.

Van Dyk & Co.
57 Wilkinson Avenue
Jersey City, N. J.

Victor Chemical Works
Board of Trade Bldg.
Chicago, Ill.

Jacques Wolf & Co.
350 Lexington Avenue
Clifton, Passaic, N. J.

Wyandotte Chemicals Corp.
Wyandotte, Mich.

Check List of Newer Organic Pesticides With Some Commonly Known Brand Names

(From *American Fruit Grower*, Vol. 75, No. 2, 1955)

Pesticide and Brand Names	*Manufacturer*
Aldrin	
Aldrin	Shell Chemical Corp.
Black Leaf Aldrin	Diamond Black Leaf Co.
Chipman Aldrin	Chipman Chemicals Ltd.
Niagara Aldrin	Niagara Chemical Div., FMC
Orchard Brand Aldrin	General Chemical Co.
Ortho Aldrin	Calif. Spray-Chemical Co.
Penco Aldrin	Pennsylvania Salt Mfg. Co.
Stauffer Aldrin	Stauffer Chemical Co.
Antibiotics	
Actidione	
Actispray	Niagara Chemical Div., FMC
Actispray	Upjohn Manufacturing Co.
Streptomycin	
Agristrep	Merck
Phytomycin	Squibb Div., Olin Mathieson Corp.
Streptomycin-Terramycin	w
Agri-mycin	Chas. Pfizer Co.
Aramite	
Aramite	U. S. Rubber Co.
Black Leaf Aramite	Diamond Black Leaf Co.
Chipman Aramite	Chipman Chemicals Ltd.
Corona Aramite	Pittsburgh Plate Glass Co.
Geigy Aramite	Geigy Chemicals Co.
Niagaramite	Niagara Chemical Div., FMC.
Orchard Brand Aramite	General Chemical Co.
Ortho-Mite	Calif. Spray Chemical Co.
Penco Aramite	Pennsylvania Salt Mfg. Co.
Stauffer Aramite	Stauffer Chemical Co.
BHC	
Benzabex	Chipman Chemicals Ltd.
Benzex	Woolfolk Chemical Works, Ltd.
BHC 10 Spray	Niagara Chemical Div., FMC
Black Leaf BHC	Diamond Black Leaf Co.
Corona BHC	Pittsburgh Plate Glass Co.
Gammacide	Calif. Spray-Chemical Co.

Pesticide and Brand Names	*Manufacturer*
Gamtox	Calif. Spray-Chemical Co.
Gy Ben	Geigy Chemical Co.
Hexadow	Dow Chemical Co.
Isotox	Calif. Spray-Chemical Co.
Lexone	DuPont de Nemours Co.
Lintox	Stauffer Chemical Co.
Orchard Brand BHC	General Chemical Co.
Penco BHC	Pennsylvania Salt Mfg. Co.
Panco Hi Gamma BHC	Pennsylvania Salt Mfg. Co.
Stauffer BHC	Stauffer Chemical Co.
Captan	
Orthocide	Calif. Spray-Chemical Co.
Stauffer Captan	Stauffer Chemical Co.
Chloranil	
Spergon	U. S. Rubber Co.
Chlordane	
Black Leaf Chlordane	Diamond Black Leaf Co.
Chipman Chlordane	Chipman Chemicals, Ltd.
Chlor Kil	Niagara Chemical Div., FMC
Corodane	Pittsburgh Plate Glass Co.
Ortho-Klor	Calif. Spray-Chemical Co.
Pratts Chlordane	B. G. Pratt Co.
Stauffer Chlordane	Stauffer Chemical Co.
Synklor	U. S. Rubber Co.
Chlorobenzilate	
Chlorobenzilate 25 W	Geigy Chemical Co.
DDD (TDE)	
Corona Rothane	Pittsburgh Plate Glass Co.
Niagara DDD	Niagara Chemical Div., FMC
Orchard Brand TDE	General Chemical Co.
Orthene	Calif. Spray-Chemical Co.
Rhothane	Rohm & Haas Co.
Stauffer DDD	Stauffer Chemical Co.
DDT	
Black Leaf DDT	Diamond Black Leaf Co.
Chipman DDT	Chipman Chemicals Ltd.
Corona 50-50 W	Pittsburgh Plate Glass Co.
DDTOL	Sherwin-Williams Co.

Pesticide and Brand Names	*Manufacturer*
D-50 Wettable	Rohm & Haas Co.
Deenate	Du Pont de Nemours & Co.
Dow DDT	Dow Chemical Co.
Geigy DDT	Geigy Chemical Co.
Genitol	General Chemical Co.
Genitox	General Chemical Co.
Niatox	Niagara Chemical Div., FMC
Penco DDT	Pennsylvania Salt Mfg. Co.
Penco Pentech	Pennsylvania Salt Mfg. Co.
Persisto	Calif. Spray-Chemical Co.
Pratts DDT	B. G. Pratt Co.
Santobane	Monsanto Chemical Co.
Demeton	
Stauffer Systox	Stauffer Chemical Co.
Systox	Chemagro Corp.
Systox	Dow Chemical Co.
Diazinon	
Diazinon 25 W	Geigy Chemical Co.
Diazinon 25 E	Geigy Chemical Co.
Diazinon Fly Bait	Geigy Chemical Co.
Dichlone	
Black Leaf Phygon	Diamond Black Leaf Co.
Kolo 100	Niagara Chemical Div., FMC
Phygon	U. S. Rubber Co.
Stauffer Phygon	Stauffer Chemical Co.
Dieldrin	
Black Leaf Dieldrin	Diamond Black Leaf Co.
Chipman Dieldrin	Chipman Chemicals Ltd.
Corona Dieldrin	Pittsburgh Plate Glass Co.
Dieldrin	Shell Chemical Co.
Orchard Brand Dieldrin	General Chemical Co.
Ortho Dieldrin	Calif. Spray-Chemical Corp.
Penco Dieldrin	Pennsylvania Salt Mfg. Co.
Stauffer Dieldrin	Stauffer Chemical Co.
Dinitros-Dormant	
Corodinoc	Pittsburgh Plate Glass Co.
Corona Dinitro Powder	Pittsburgh Plate Glass Co.
Dinitro Dry	Niagara Chemical Div., FMC.

Pesticide and Brand Names	*Manufacturer*
DN Drymix No. 1	Dow Chemical Co.
DN Drymix No. 2	Dow Chemical Co.
DN-289	Dow Chemical Co.
Elgetol 30	Standard Agri. Chem. Co.
Elgetol 318	Standard Agri. Chem. Co.
Krenite 26	Du Pont de Nemours & Co.
Nitro Vaporol	Calif. Spray-Chemical Corp.
Dinitros-Summer	
DN-111	Dow Chemical Co.
Endrin	
Black Leaf Endrin	Diamond Black Leaf Co.
Chipman Endrin	Chipman Chemicals Ltd.
Endrin	Shell Chemical Corp.
Endrin	Velsicol Chemical Corp.
Penco Endrin	Pennsylvania Salt Mfg. Co.
Stauffer Endrin	Stauffer Chemical Co.
EPN	
EPN 300	Du Pont de Nemours & Co.
Ferbam	
Black Leaf Ferbam	Diamond Black Leaf Co.
Carbamate	Niagara Chemical Div., FMC
Chipman Ferbam	Chipman Chemicals Ltd.
Coromate	Pittsburgh Plate Glass Co.
Fermate	Du Pont de Nemours & Co.
Ferradow	Dow Chemical Co.
Karbam Black	Sherwin-Williams Co.
Nu-Leaf	Calif. Spray-Chemical Corp.
Orchard Brand Ferbam	General Chemical Co.
Penco Ferbam	Pennsylvania Salt Mfg. Co.
Genite 883	
Genite 883	General Chemical Co.
Glyodin	
Crag Fruit Fungicide 341	Union Carbide Chemicals Co.
Heptachlor	
Black Leaf Heptachlor	Diamond Black Leaf Co.
Chipman Heptachlor	Chipman Chemicals Ltd.
Geigy Heptachlor	Geigy Chemical Co.
Heptachlor	Velsicol Chemical Corp.

Pesticide and Brand Names	*Manufacturer*
Ortho Heptachlor	Calif. Spray-Chemical Corp.
Stauffer Heptachlor	Stauffer Chemical Co.
Karathane	
Karathane	Rohm & Haas Co.
Mildex	Larvacide Products, Inc.
LINDANE	
Black Leaf Lindane	Diamond Black Leaf Co.
Chipman Lindane	Chipman Chemicals Ltd.
Dow Lindane	Dow Chemical Co.
Geigy Lindane	Geigy Chemical Co.
Isotox	Calif. Spray-Chemical Corp.
Niagara Lindane	Niagara Chemical Div., FMC
Orchard Brand Lindane	General Chemical Co.
Penco Hi Gam	Pennsylvania Salt Mfg. Co.
Penco Lindane	Pennsylvania Salt Mfg. Co.
Pratts Lindane Spray	B. G. Pratt Co.
Stauffer Lindane	Stauffer Chemical Co.
Malathion	
Black Leaf Malathion	Diamond Black Leaf Co.
Chipman Malathion	Chipman Chemicals Ltd.
Corona Malathion	Pittsburgh Plate Glass Co.
Geigy Malathion	Geigy Chemical Co.
Malathion	American Cyanamid Co.
Malathion 50 Spray	Niagara Chemical Co.
Orchard Brand Malathion	General Chemical Co.
Ortho Malathion	Calif. Spray-Chemical Corp.
Penco Malathion	Pennsylvania Salt Mfg. Co.
Pratts Malathion Spray	B. G. Pratt Co.
Stauffer Malathion	Stauffer Chemical Co.
Maneb	
Dithane M-22	Rohm & Haas Co.
Manzate	DuPont de Nemours & Co.
Metacide	
Metacide	Chemagro Corp.
Methoxychlor	
Chipman Methoxychlor	Chipman Chemical Ltd.
Geigy Methoxychlor	Geigy Chemical Co.
Marlate	DuPont de Nemours & Co.

Pesticide and Brand Names	*Manufacturer*
Methoxcide	Niagara Chemical Div., FMC.
Orchard Brand Methoxychlor	General Chemical Co.
Orthotox	Calif. Spray-Chemical Corp.
Stauffer Methoxychlor	Stauffer Chemical Co.
Nabam	
Dithane D-14	Rohm & Haas Co.
Liquid Parzate	DuPont de Nemours & Co.
Ortho Nabam	Calif. Spray-Chemical Corp.
Thiodow	Dow Chemical Co.
Organo-Mercury	
Coromerc	Pittsburgh Plate Glass Co.
Puratized Agricultural Spray	Gallowhur Chemical Corp.
Puratized Apple Spray	Gallowhur Chemical Corp.
Stauffer Phenyl Mercury Lactate	Stauffer Chemical Co.
Tag	Calif. Spray-Chemical Corp.
Ovex	
Orthotran	Calif. Spray Chemical Corp.
Ovotran	Dow Chemical Co.
Stauffer Ovex	Stauffer Chemical Co.
Parathion	
Black Leaf Parathion	Diamond Black Leaf Co.
Chipman Parathion	Chipman Chemicals Ltd.
Corothion	Pittsburgh Plate Glass Co.
Dow Parathion	Dow Chemical Co.
Geigy Parathion	Geigy Chemical Co.
Genithion	General Chemical Co.
Niran	Monsanto Chemical Co.
Orthophos	Calif. Spray-Chemical Corp.
Panthion	Woolfolk Chemical Works, Ltd.
Paradust	Stauffer Chemical Co.
Penco Parathion	Pennsylvania Salt Mfg. Co.
Phos Kil	Niagara Chemical Div., FMC.
Stauffer Parathion	Stauffer Chemical Co.
Vapophos	Calif. Spray-Chemical Corp.
Quaternary Ammonium Compounds	
Purasan AD 50	Gallowhur Chemical Corp.
Stanofide	Standard Oil of Ind.

Pesticide and Brand Names	*Manufacturer*
Quinones	
Black Leaf Phygon	Diamond Black Leaf Co.
Kolo 100	Niagara Chemical Div., FMC
Phygon	U. S. Rubber Co.
Spergon	U. S. Rubber Co.
Stauffer Phygon	Stauffer Chemical Co.
TEPP	
Black Leaf TEPP 40	Virginia-Carolina Corp.
Mulsifos	Woolfolk Chemical Works
Niagara TEPP	Niagara Chemical Div., FMC
Orchard Brand TEPP	General Chemical Co.
Pyfos	Woolfolk Chemical Co.
Stauffer TEPP	Stauffer Chemical Co.
Vapotone	Calif. Spray-Chemical Corp.
Toxaphene	
Altox	Calif. Spray-Chemical Corp.
Black Leaf Toxaphene	Diamond Black Leaf Co.
Chipman Toxaphene	Chipman Chemicals Ltd.
Geniphene	General Chemical Co.
Gy-Phene	Geigy Chemical Co.
Penco Toxaphene	Pennsylvania Salt Mfg. Co.
Stauffer Toxaphene	Stauffer Chemical Co.
Toxakil	Niagara Chemical Div., FMC
Urea	
NuGreen	DuPont de Nemours & Co.
Zineb	
Dithane Z-78	Rohm & Haas Co.
Ortho Zineb	Calif. Spray-Chemical Corp.
Parzate	DuPont de Nemours & Co.
Stauffer Zinez	Stauffer Chemical Co.
Thiodow	Dow Chemical Co.
Ziram	
Corozate	Pittsburgh Plate Glass Co.
Karbam White	Sherwin-Williams Co.
Opalate	Calif. Spray-Chemical Corp.
Orchard Brand Ziram	General Chemical Co.
Stauffer Ziram	Stauffer Chemical Co.
Z-C Spray	Niagara Chemical Div., FMC
Zerlate	DuPont de Nemours & Co.

Addresses of Manufacturers on Pages 585-591

American Cyanamid Co.
30 Rockfeller Plaza
New York, N. Y.

California Spray-Chemical Corp.
Lucas and Ortho Way
Richmond, Calif.

Carbide & Carbon Chemical Co.
30 E. 42nd St.
New York 17, N. Y.

Chemagro Corp.
437 Fifth Avenue
New York 16, N. Y.

Chipman Chemical Co.
P. O. Box 309
Bound Brook, N. J.

Diamond Black Leaf Co.
300 Union Commerce Bldg.
Cleveland 14, Ohio

The Dow Chemical Co.
Midland, Mich.

E. I. Du Pont de Nemours & Co., Inc.
Grasselli Chemicals Dept.
1007 Market Street
Wilmington 98, Del.

Gallowhur Chemical Corp.
N. Water Street
Ossining, N. Y.

Geigy Agricultural Chemicals
Saw Mill River Road
Ardsley, N. Y.

General Chemical Division
Allied Chemical & Dye Corp.
40 Rector Street
New York 6, N. Y.

Larvacide Products, Inc.
117 Liberty Street
New York 6, N. Y.

Merck & Co., Inc.
Rahway, N. J.

Monsanto Chemical Co.
800 N. Twelfth Boulevard
St. Louis 1, Mo.

Niagara Chemical Division
Food Machinery & Chemical Corp.
100 Niagara Street
Middleport, N. Y.

Olin Mathieson Chemical Corp.
Mathieson Bldg.
Baltimore 3, Md.

Penna. Salt Manufacturing Co.
of Washington.
2901 Taylor Way
Tacoma, Wash.

Chas. Pfizer & Co.
630 Flushing Avenue
Brooklyn, N. Y.

Pittsburgh Plate Glass Co.
Moorestown, N. J.

B. G. Pratt Co.
204-208 21st Avenue
Paterson 3, N. J.

Rohm & Haas Co.
222 W. Washington Square
Philadelphia 5, Pa.

Shell Chemical Corp.
460 Park Avenue
New York 22, N. Y.

Squibb Division
Olin Mathieson Chemical Corp.
Mathieson Bldg.
Baltimore 3, Md.

Standard Agricultural Chemicals, Inc.
1301 Jefferson Street
Hoboken, N. J.

Standard Oil of Indiana
910 South Michigan Avenue
Chicago 80, Ill.

Stauffer Chemical Co.
380 Madison Avenue
New York 17, N. Y.

U. S. Rubber (Naugatuck) Division
Naugatuck, Conn.

Upjohn Company
301 Henrietta Street
Kalamazoo 99, Mich.

Velsicol Chemical Corp.
330 E. Grand Avenue
Chicago 11, Ill.

Virginia-Carolina Chemical Corp.
Box 1136
Richmond 8, Virginia

Woolfolk Chemical Works Ltd.
East Main Street
Fort Valley, Ga.

The Grumman "Ag Cat"

AT this date, (January, 1958), the most recent development in the agricultural aviation field is a new plane for aerial agricultural application, the "Ag Cat" put into production early in 1958 by the Grumman Aircraft Engineering Corporation, Bethpage, Long Island, New York (See picture on frontispiece). The new crop dusting ship is a biplane and its unique design combines maximum wing area, with minimum wing span. Many crop dusting accidents have been found to result from stalls during the "turn-around." The "Ag-Cat" is reported to execute a continuous 1.5G turn at the dusting speed and at a maximum gross weight. In this particular design, the wings, not the engine carry the major load. Upper and lower wings are interchangeable, and are torsionally stiffened, with a minimum of external wires.

Other features of the Ag-Cat are a sloping nose to offer maximum visibility; a gentle stall at low speed, emergency dump valve to empty the hopper rapidly, and oversized disc brakes. A notable design factor is instant change from dust to liquid application.

Performance features of the plane include: a maximum level speed of 110 mph; stall speed of 42 mph; take off distance at 2600 lbs. of 330 feet,—with 3600 lbs., distance is 675 feet; rate of climb at 2600 lbs. is 940 fpm,—at 3600 lbs. climb is 530 fpm. Endurance (220 hp Continental @ 1750 rpm) is three hours.

Literature Cited

Anonymous. 1955. Chemical Weed Control Recommendations. Miss. Agr. Exept. Sta. Cir. 195, 26 pp., illus.

Bailey, S. F. and L. M. Smith, 1951. Handbook of Agricultural Pest Control. Industry Publications, Caldwell, N. J., 191 pp., illus.

Blodgett, F. M. and E. O. Mader. 1934. A method of recording the distribution of copper dusts or sprays on leaves. *Phytopathology* 24:418-422, illus.

Courshee, R. J., F. X. Daynes, and J. B. Byass. 1954. A tree spraying machine. National Institute of Agricultural Engineering (NIAE) publications, England.

Davis, J. M. 1949. A photographic method for recording size of spray drops. U.S.D.A. Bur. Ent. and Plant Quar., ET-272, illus.

———————. 1951. A vibratory apparatus for producing drops of uniform size. U.S.D.A. Bur. Ent. and Plant Quar., ET-295, 3 pp. (In cooperation with the Div. of Farm Machinery, BPISAE).

——————— and K. R. Elliot. 1953. A rapid method for estimating aerial spray deposits. *Jour. Econ. Ent.* 46(4):696-698.

Hamilton, C. C. and C. M. Smith. 1925. A colorimetric method for showing the distribution and quantity of lead arsenate upon sprayed and dusted surfaces. *Jour. Econ. Ent.* 18(3):502-508.

May, K. R. 1945. The cascade impactor. An instrument for sampling coarse aerosols. *Jour. Sci. Instr.* 22:187-195.

Nelson, R. H. 1952. Conversion tables and equivalents for use in work relating to insect control. U.S.D.A. Bur. Ent. and Plant Quar., E-517, 20 pp.

Poos, F. W., T. N. Dobbins, and R. H. Carter. 1950. Sampling forage crops treated with organic insecticides for determination of residues. U.S.D.A. Bur Ent. and Plant Quar., E-793.

Rayner, A. C. and Wm. Haliburton. 1955. Rotary device for producing a stream of uniform drops. Rev. of Sci. Instruments 26(12):1124-1127.

Ripper, W. E. 1955. Application methods for crop protection chemicals. Ann. Appl. Biol. 42:288.

Yeomans, A. H. 1949. Directions for determining particle size of aerosols and fine sprays. U.S.D.A. Bur. Ent. and Plant Quar., ET-267, 7 pp.

———————. 1955. A method of determining particle size of liquefied-gas aerosols. U.S.D.A., Agr. Res. Serv., mimeo paper No. 33-5.

———————. and E. E. Rogers. 1953. Factors influencing deposit of spray droplets. *Jour. Econ. Ent.* 46(1):57-60.

——————— and E. R. Van Leeuwen. 1954. Insecticide spray deposits. *Soap and Sanitary Chem.* 30(4):141.

INDEX

acaricides 376
aerial application
  legal requisites 285
  materials 285
  of herbicides 335
  safety in 341
  valves for 289
aeroplane sprayer, definition 13
aerosols—Chapter 7 493
  application of 514
  definition 10
  field 498
  field model machines 501
  generator for 508
  greenhouse 496
  liquefied sprays 23
  mechanically produced 131
  nozzle type machines for 502
  particle size of 517
  thermal 501
  thermal smoke 25
  windborne 509, 511
aircraft—Chapter 4 277
  boomstays for 300
  biplane equipment 303
  Grumman "Ag Cat" 593
  helicopters 342
  miscellaneous equipment for 301
  multi-engine plane 313
  N2S installation 307
  pumps for 297
  rates of coverage 103
  special designs of 293
  tanks for 293
  types of 291
air streams 58
atomization 101
  hot gas 513

Bean sprayer, John 141
booms 215, 232, 354
boomless sprayer 223
Brann crop machine 157
Brann outlet 177
Brann nozzle 184
Buffalo Turbine Co., sprayer 140, 141

calibration 94, 105
  using Spraying Systems nozzles 568
citrus spraying 414
clover, sprayer for 161, 229
concentrate sprays 17
corn
  mist blowers for 163
  sprayer for 231
  weed control in 441
corrosion of aircraft materials 109
costs of commercial operations 234
cotton
  chemical defoliation 445
  hand sprayer in 205
  low gallonage equipment for 202
  mist blower for 163
  weed control in 441
Cub monoplane 292

decimal equivalents 557
defoliation, chemical 453-460
deposition rates 71
  on low vegetation 91
Douglas DC-3 292
drop size 533
  vibratory apparatus for 534
dusts 15
  aerial application of 349

emulsifying agents 367
  manufacturers of 584
emulsions 551
equivalents
  common 546
  concentration units 550
  decimal 557
  linear and area 547
  mass, capacity 543
  weight and volume 389

Farquhar, A. B., sprayer 137, 139
fertilizer sprays 403
field crops
  equipment for 229
  mist blower for 163
  weed control in 441
Fog Air swingfog 504
foliage spraying 408-415
formulation
  aerosols 514
  specifications for 582
  spray 418
fungicides 376-380

grain fields
  equipment for 229
  sprayer for 165
  Grumman "Ag Cat" 593

hand equipment 44, 237, 241, 249, 250
hang-on blowers 172
Hardie sprayer 164, 165, 289
helicopter application 342
herbicides 429
  aerial application of 335
  glossary of terms 487
  oil 436
  use of 467
highway weed control 470
horticultural crops, weed control in 437
household sprays 401

insecticides
  aerosol 495
  botanical 371
  charts for calculation of mixtures 111, 380
  chlorinated hydrocarbon 373
  compatibility of 401
  dilution calculations 549
  for red mites 162
  for home gardens 363
  inorganic 369
  mixtures of 359
  organic 370
  soil pest control 239
  synthetic 373

instruction information 286, 565, 571

knapsack mist blower 243, 253

lead arsenate 369, 542
liquid fertilizers 403-407
livestock sprays 499
low gallonage
  equipment 12, 199, 219, 227

Meyers, F. E., sprayer 164
mist blower 119, 131-150
  A. B. Farquhar 137, 139
  applications with 57
  bid specifications 137
  Bean, John 141
  Buffalo Turbine 140, 141
  in citrus groves 191
  Cornell row crop 157
  definition 12
  for tall shade trees 135, 137
  for plantations, turf 135
  Hardie 144, 145
  lateral deposits of 69
  light weight 145, 155
  operation of 245
  Rotomist 140
  trailer mounted (150

nursery stock
  mist blower for 160, 161
  red mites in 162

Oliver, Iron Age sprayer 167

- operators
  - aerial aircraft 281, 337
  - pest control examination for 575
  - for tree spraying 131
- orchard equipment 169
  - mist blowers 191
  - air blast machines 199
- outlets 152, 156, 173, 177, 179, 183, 197

- paint sprayer 235
- particle size 326, 517-9, 523-5
- pastures
  - sprayer for 165, 229
  - weed control in 415
- protective equipment 339
- pumps 211, 221, 287, 297
- public relations in weed programs 478

- row crop sprayer
  - F. E. Meyers 164
  - Hardie Mfg. Co. 164
  - Oliver Iron Age 167
- row crop spraying with mist blower 155
- Rotomist 140
- respirators 581, 582

- screen deposit tests 65
- silvicides 479
- soil injection equipment 265
  - supplies 266
- spray
  - formulas 112
  - mixtures—Chapter 3 359
  - sampling 532
- spray delivery 89, 104
  - deposit and dropsize tests 153
  - diameter calculations 123
  - for different sized outlets 122
  - spray patterns in 101, 530, 532
- spray deposit 27, 65, 171
  - calculations 538
  - dye method determination 538
  - comparison vs dust deposit 49
- spray-dust application 51, 53
- spray equipment
  - aerial—Chapter 4 277
  - adaptations 187, 203
  - calibration on farm 94
  - definition 12
  - ground—Chapter 3 115
  - manufacturers of 273, 344
  - nozzles for 84, 127, 184, 203, 222, 327, 364, 560, 558
  - portable 244
  - speed sprayer 181
  - tanks and agitators for 129
  - valves for 130
  - wheelbarrow model 243, 247
- sprays
  - concentrated 17
  - fertilizer 404
  - household 401
  - how to determine amount to use 60, 364
- spraying
  - aerial 21
  - day vs night 173
  - foliage 408
  - ground 21
- spread factor 522, 528, 529
- Stearman biplane 292
- stickers 367
- swaths 88, 321, 315, 351

- tanks 207, 219
  - for aerial application 286, 293
  - time to empty 559
  - volume calculations 555, 558
- terminology—Chapter 2 7
  - herbicide glossary 487
- Todd Fog applicator 504
- tractor speeds 565
- tree spraying 131
  - air displacement in 563
  - aerial 316
- tree spraying
  - Coverage 82
  - day vs night 173
  - forest spraying 323
  - mist blowers for 73, 135, 195
  - outlets for 173
  - requisites in 362
- turf and lawns—weed control in 452

water hardness values 566
weed control—Chapter 6 423
  aerial 481
  chemicals for 429
  climatic factors 485
  cost of 422
  equipment for 229, 448
weed control
  in field crops 441
  in horticultural crops 437
  in turf 457
  organization 424
wetting agents 367
wheelbarrow sprayer 234, 247

LIBRARY
INSTITUTE, *

hecked
23/4/62

11.989

CHECKED

1-5-97

ECKED
2008

VERIFIED
2013

CFTRI-MYSORE
4938
Concentrated spr..

— 25.1.78 23.1.78

12.5.94